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FRONTISPIECE.

Smoky-quartz.

St. Gotthard, Switzerland (*from a specimen in the Karlsruhe collection*).

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THE MINERAL KINGDOM

BY

DR. REINHARD BRAUNS
PROFESSOR OF MINERALOGY IN THE UNIVERSITY OF BONN

TRANSLATED, WITH ADDITIONS, BY

LEONARD J. SPENCER, M.A., F.G.S.
OF THE MINERAL DEPARTMENT, BRITISH MUSEUM
EDITOR OF THE MINERALOGICAL MAGAZINE

WITH 91 PLATES (73 OF WHICH ARE COLOURED)
AND 275 TEXT-FIGURES

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Translation of Author's Preface.

This book has been written for the admirers and collectors of minerals, and aims at increasing the number of persons interested in these natural objects. It is not a text-book of Mineralogy, but a popular book dealing with such parts of the science as are of general interest and usefulness. The most important minerals are represented in their natural form, colour, and size on 73 chromo-lithographic plates, and in addition there are 14 photographic reproductions, 4 art-plates, and numerous figures in the text.

It is not all minerals that are suited for pictorial representation; and in any case the specimens must be carefully selected, so that they will show to advantage any particular mineral without giving too much prominence to the associated materials. For this purpose a collection such as that in the University of Giessen does not suffice, and I have had to rely on the kind support of colleagues and friends. The specimens here portrayed belong to the Museums of the Universities of Bonn, Göttingen, and Marburg, the Natural History Museums of Stuttgart, Karlsruhe, and Hamburg, the Senckenberg Museum at Frankfurt, and that of the Mining Academy at Clausthal. To the custodians of these collections — namely, to Professors H. Laspeyres, T. Liebisch, M. Bauer, E. Fraas (and Dr. E. Schütze), M. Schwarzmann, C. Gottsche, W. Schauf, and A. Bergeat, respectively — my best thanks are due for the loan of valuable specimens; and also to Mr. Gustav Seligmann of Coblenz, who has placed at my disposal the treasures in his private collection. A few other specimens have also been loaned by Professors F. Berwerth of Vienna, V. Goldschmidt of Heidelberg, E. Kalkowsky of Dresden, A. Nies of Mainz, A. Sauer of Stuttgart, Mr. Hermann Stern of Oberstein, and the Brothers Görlitz of Idar. Most of the photographs reproduced on the plates and in the text-figures have been taken by Dr. Heineck, whilst those of the optical interference-figures were supplied by Dr. Hans Hauswaldt of Magdeburg. To all of these I express my hearty thanks. My thanks are also due to the publisher, who has spared no cost, and to the proprietors of the art-works of Wahler and Schwarz, who have spared no pains, in order that the result should be the best attainable. The improvement effected in the work during the three years necessary for the preparation of the plates may be seen from a comparison of plates 46 and 48, which were issued with the first part, and the frontispiece (smoky-quartz), which came out in one of the later parts of the book. The drawings of crystals for the text-figures have been taken from the well-known works of Dana, Groth, Koksharov, Naumann-Zirkel, Tschermak, and other authors. Except in a few special cases, references to the literature have not been given.

In the descriptions, I have endeavoured, so far as the subject-matter allows, to express myself as clearly and simply as possible; and I hope that the reader will be able to follow without further help.

The volume commences with a *General Part* in which is given a brief account of the more important characters of minerals — their crystalline form, physical properties,

and chemical composition — sufficient, however, to make clear the terms used in the succeeding descriptive part. In the *Special or Descriptive Part* particular reference is made to the applications and uses of minerals, and to the part they play in Nature. It is also on these principles that the minerals are classified, rather than on the more strictly scientific methods adopted in text-books on Mineralogy. Thus, the first section includes the *Ores* and their associated minerals, and is illustrated by 32 coloured and 3 uncoloured plates. In conjunction with the ores proper other minerals which result from the weathering of these are also dealt with: for example, cerussite, pyromorphite, and other salts of lead come next to galena; and malachite and chessylite with the ores of copper. The amounts of the production during recent years are quoted for each metal. Meteorites are considered in an appendix to the ores of iron, and are illustrated by one coloured and two uncoloured plates.

The second section treats of the *Precious Stones* and allied minerals, and is illustrated by 16 coloured and 4 uncoloured plates. Here the description of diamond is followed by that of graphite, and as an appendix to corundum some mention is made of those minerals used for the extraction of aluminium. For many of the statements in this section I am indebted to Mr. Koch, court jeweller of Frankfurt, Mr. Tornow, also of Frankfurt, and to Mr. Görlitz and Mr. Hermann Wild of Idar.

The third section of the descriptive part includes the *Rock-forming Minerals*, which, though usually inconspicuous in appearance, are of great importance in that they constitute the bulk of the materials of the earth's crust. Three photographic plates represent these minerals as seen under the microscope in thin sections prepared from rocks, while, in addition, 9 coloured plates represent the minerals themselves.

In the fourth section, illustrated by 11 coloured and 2 uncoloured plates, are included those minerals, such as rock-salt and phosphates, which are necessary to the life and growth of animals and plants, and which are employed in large quantities by the chemical manufacturer. Amber, though not strictly a mineral, is next dealt with.

The distribution of the minerals on the plates was necessarily governed by the space available, and consequently they do not all fall into quite the places where they might be expected. Further, during the course of the work, it was considered advisable to give some additional plates (e.g. 2a, 29a, etc.).

The work was undertaken with some trepidation, but with the support received from many quarters it has, as I hope, not been unsuccessful. So may the book go into the world to give joy to the amateur, pleasure to the expert, encouragement to the learner, support to the teacher, and hints to the practical man; but also may it encourage and extend the study of our science in wider circles.

Giessen, 15 September 1903.

REINHARD BRAUNS.

Note by Translator.

No attempt has been made to give an exact literal translation, but the arrangement and matter of the original have been strictly preserved. Certain points have been slightly modified to meet the needs of English readers. This applies more particularly to the enumeration of the localities at which the various minerals have been found; some of the German occurrences of lesser importance having been replaced by others belonging to English-speaking countries. Slight additions have been made throughout where new points of sufficient general interest seemed worthy of mention; and the tables giving the amounts of production of various useful minerals have been made out for recent years.

The 440 pages of the German original have been rendered into 432 pages of the same size in the English translation. The general part has been increased by five pages and the index by three pages, and there has been a curtailment of the special or descriptive portion to the extent of sixteen pages. The numerous plates are given exactly as in the German edition.

The original German edition appeared in parts during the years 1903 and 1904, and the work has since then been translated into Russian, Italian, and Bohemian. The present English edition should find a still wider circulation amongst the English-speaking mining communities in all quarters of the globe.

This English edition has been printed and published in Germany, and its tardy appearance in parts during 1908 to 1912 has been occasioned by two changes in the publishers. The German publishers and printers deserve much credit for their work, but there having been no press-reader a large amount of additional labour has fallen to the translator in correcting the proofs. Unfortunately, for this reason, several printer's errors of minor importance have escaped notice. These are not always readily detected, but are quite obvious when pointed out, so obvious, in fact, that a list of errata seems unnecessary. My colleague, Mr. W. Campbell Smith of the Mineral Department, British Museum, has kindly given me help in reading the proofs of the last few parts, and it is hoped that here practically all the printer's errors have been eradicated.

June 1912.

L. J. S.

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Introduction.

The Mineral Kingdom.

The Mineral Kingdom comprises the cold and lifeless stones which form the crust of our earth. Although these stones are themselves lifeless, yet the materials of which they are composed are essential to the existence of all things in which life has been awakened by the warmth of the sun. On this account alone then, the study of minerals will engage our serious attention. But apart from this claim on our interest, we are attracted by the beautiful colours, brilliant lustre and great hardness of certain minerals. Such stones as these have been used in all ages for personal ornament; they have not the fleeting beauty of flowers but are beautiful for all time. Not so with their imitations. However cleverly the imitation be made, it never equals the genuine stone in richness of colour or brilliancy of lustre, and after a very short period of wear it becomes scratched and dull, while the real stone retains its beauty unimpaired to delight the eyes of its possessor.

Precious stones are used only for ornament; they cannot therefore be said to have aided greatly in the slow growth of civilization. With metals, however, it has been far otherwise. What indeed would be the condition of the human race to-day if suddenly deprived of gold, silver, copper and iron? Here again, it is from the earth's crust that these valuable metals are obtained, not indeed in metallic form, but combined with other minerals and, as it were, disguised. The practised eye recognises these mineral combinations as metallic ores and they are won from the bowels of the earth by the patient and laborious efforts of the miner. The fruit of his labour furnishes the world with the material for the construction of tools and machinery, railways and telegraphs, and with gold, the precious metal which serves as a standard of currency. Glass, porcelain and oil-of-vitriol may be mentioned among the many substances prepared in the great centres of chemical industry from materials derived from the earth's crust. There is not a moment in our lives when we could dispense with the services rendered us by the mute and inanimate mineral kingdom.

The Limits of the Mineral Kingdom.

In a sense the Mineral Kingdom is universal, for it embraces not only the whole earth, but also meteorites, those celestial messengers which come to us out of the depths of the stellar universe. Some members of this immense kingdom have, as it were, taken up their abode in other domains, and like the colonies to the mother-country

retain only a loose connection with the mineral kingdom. Such are the fossils, those petrified remains of animals and plants which are found embedded in hard rock. While they show any trace of organised structure fossils are excluded from the mineral kingdom, for in that domain is included nothing which lives or has once lived. When, however, such changes in the fossil have taken place that it loses the shape and form originally impressed on it by the vital activity of the creature of which it formed a part, it ceases to be a fossil and is once more included in the mineral kingdom. The emigrant returns to the mother-country.

As an illustration, let us consider a slab of limestone (fig. 1), which when cut and polished as a table-top or other object shows markings which are easily recognised

Fig. 1.
Coral-limestone, from Bieber, Hesse.

Fig. 2.
Calcite in altered coral-limestone: Bieber, Hesse.

as sections of corals. The stone indeed consists almost entirely of remains of corals, and in therefore classified with the fossils. Such a limestone may, however, by changes in the earth's crust or on the surface undergo such a transformation in character that all trace of organic structure disappears, and instead we notice forms with sharp edges and plane surfaces which we call calcite crystals (fig. 2). The specimen represented by fig. 2 was collected from the same quarry as that shown in fig. 1. The original coral-limestone has been partly dissolved by the action of subterranean water percolating through it, and from this solution the carbonate of lime has been redeposited in the form of

crystals in the cavities of the rock. The two specimens are thus identical in substance, but different in form.

Fossils are separated from the mineral kingdom and form a domain which it is the business of the palaeontologist to explore. Together with living things they constitute the organic world, of which the lowliest member is the cell and the highest man.

Rocks and Minerals.

In contra-distinction to the organic world, the inorganic world is and has ever been without life; its members possess no organs, nor do they show the cells characteristic of living organisms. In the inorganic world we include both the rocks which form the greater part of the earth's crust, and the minerals distributed among these rocks. But then arises the question how to discriminate between a rock and a mineral, and which constituents of the earth's crust belong to the mineral kingdom in the narrower sense of the term.

The answer to this question has not always been the same, and with the advance of knowledge we are able now to draw a more sharply defined boundary between minerals and rocks. We may regard a mineral as an entity, as it were, of the inorganic kingdom. While a rock we regard as an association of mineral entities.

There is more difference between minerals and fossils, which belong to separate kingdoms, than between minerals and rocks, which are included in the same kingdom, a rock, indeed, being simply an association of minerals.

A rock which is familiar to all is granite. It is easy to see that this rock is composed of materials of different kinds: dark, shining scales; dull, reddish grains; and greyish grains shining like glass. The dark, shining scales consist of the mineral mica; the reddish grains of the mineral felspar; and the greyish grains of the mineral quartz. Granite is therefore a rock, the mineral constituents of which are mica, felspar and quartz.

It is not, however, always as easy to decide whether any given specimen should be regarded as a mineral or a rock, that is to say, whether it consists of a single mineral substance or of an association of minerals, and in such cases it may be necessary to enlist the aid of the microscope or of chemical analysis. When examined under the microscope the specimen, if a mineral, appears homogeneous; if a rock, it presents a heterogeneous appearance. The appeal to chemical analysis is even more decisive. The mineral will be found to consist of one element or of several, and if of several, the elements will be combined, in accordance with the law of chemical combination in multiple proportions, to form a chemical compound. The rock, on the other hand, will consist of elements which are not combined together in any definite proportions. In other words, rocks are not chemical compounds but are mixtures.

The answer to our question "What is a mineral and what is a rock?" can therefore be given as follows: —

Minerals are chemical elements or inorganic chemical compounds occurring in the earth's crust: rocks are mixtures of minerals.

Compounds prepared by the chemist in the laboratory although possessing all the characters of true minerals are yet not minerals, since they have not been formed in the earth's crust. Minerals are always natural products.

Thus metallic copper is found as a chemical element in the earth's crust, and as such is a mineral. But metallic copper which has been extracted from an ore of copper by smelting is not a mineral, since it has been produced by human agency. Again, iron-pyrites is a mineral; it is composed of the elements iron and sulphur combined in the atomic proportion 1:2. On the other hand, obsidian, although it is often homogeneous in structure, is not a mineral, since it is not a definite chemical compound. To take another example, sodium chlorate, though a definite chemical compound, is not a mineral, since it does not occur in nature. Pearls and corals are not minerals, for they have been formed by the agency of animals, and therefore belong to the organic kingdom. Amber in the same way is a product of the vegetable world, but, since the traces of its vegetable origin are lost and it is found in the ground, it is often regarded as a mineral. Following long-established custom, therefore, we shall include it with true minerals and treat of it in detail at the end of this volume.

The investigation of the characters and relationships of minerals belongs to the science of *mineralogy*, which deals also with the mode of occurrence of minerals, their origin and alterations. It is not our intention to deal with all minerals in this work, since many are very rare or have only a scientific interest, while others are so inconspicuous or occur in such small particles that they cannot be well represented in a figure or plate. We shall therefore describe in this place only the most important minerals, but before passing to their consideration it will be well to acquaint ourselves with the general characteristics of mineral species. As in the case of common objects, it is the most superficial characters which first strike the eye, so in considering minerals we will first turn our attention to their most salient characteristic, that is to say, to their external form, endeavouring at the same time to avoid any unnecessary calculations or formulae.

Every mineral possesses a certain set of characters which serve to distinguish it from all other minerals and to enable the mineralogist to recognise it under any conditions. Take, for example, the minerals of which granite is composed: the dark scales of mica are characterised by the fact that they are easily scratched with a knife and that they can be split up into thin leaves, and these again into still thinner leaves, the surface along which the splitting takes place being always smooth and brilliant. The reddish grains of felspar also show smooth cleavage surfaces, but it is only with difficulty that comparatively thick flakes of the mineral can be split off parallel to this surface, and it is with difficulty also that it can be scratched with a knife. From the grey grains of quartz only splinters, like splinters of glass, can be obtained, and the fractured surface is splintery instead of being smooth. Moreover, it is impossible to scratch quartz with a knife, and if the trial be made the knife loses its edge in the process. These three minerals therefore are distinguished by their different fractures and different degrees of hardness. By familiarising ourselves with some of the commonest characteristics of minerals we shall be enabled to recognise them under whatever conditions we meet them. The process of familiarising ourselves with the more obvious features of common minerals will be easier if we choose for observation, not rocks which are mixtures of minerals, but crystals consisting of one single mineral, the characters of which are sufficiently easy to decipher.

The Form of Minerals.

Crystals.

In a granite quarry there are sometimes to be seen small cavities and clefts in the solid rock; these cavities not infrequently contain minerals firmly fixed to their walls. Here we recognise again the same minerals as before; the dull, cloudy felspar breaking with smooth fractures (shown in the upper part of fig. 1, plate 1), the hard glassy quartz (lower part of the same figure), and perhaps also shining scales of mica. But these same minerals, which we before saw as grains in the solid rock, have now quite a different form. They will be seen to be bounded by plane faces with sharp edges and corners. They have, indeed, quite the appearance of solid forms or models which have been cut and polished by the hand of man. But it is clear that they must have originated in the solid rock itself, for they were first brought to light when the cavities were broken into by the quarry-man: they had never before been seen by man nor touched by his hand.

The shapes of these bodies are different for each of the different minerals; indeed, this feature alone is sufficient to distinguish one mineral from another, as we found previously in the case of the other characters. The mica has the form of thin, six-sided plates, which, as before, can be easily split into thin leaves parallel to the surface of the plate. The felspar is less plate-like in form and exhibits several broad and dull surfaces. Lastly, the quartz is in the form of short columns with shining faces, the column being bounded by six striated faces and terminated by six smooth faces (see fig. 1, plate 1).

The question may naturally be asked how have these shapes originated and why are they different for each mineral. If we do not believe in mountain elfs and goblins, the only answer can be that the minerals have of themselves grown in these shapes, just as a snail builds its own house. The material, though not possessed of life, has the power to form itself in shapes bounded by plane surfaces. On what character of the material this property depends we do not know. Since the destruction of the form requires the exertion of some force, we must assume that some force has acted in the production of the form, this force being inherent in the substance. Such a form, bounded by plane surfaces, which a mineral assumes of its own accord, we call a *crystal*. This word is derived from the Greek, and originally signified ice. The name was at first applied to the transparent quartz found in cavities in the granite of the Alps, under the belief that it really was ice, which by prolonged exposure to intense cold had become so hard that it could not be again thawed. This belief found some support in the fact that the quartz contained green needle-like enclosures suggestive of grass (fig. 9, plate 54). Later, the word crystal came to be applied to all the regular forms which minerals assume.

Other substances, besides minerals, possess this property of forming themselves into crystals; a fact which may be demonstrated by a very simple experiment. This is performed by dissolving ordinary alum in warm water, the liquid being stirred and the alum added in a powdered form until no more will dissolve (100 parts by weight of water will dissolve 12 of alum). The saturated solution is allowed to stand over-night, and in the morning there will seen, at the bottom of the liquid, crystals of alum with plane and bright surfaces. These are crystals, just as much as are the shapes assumed by minerals; the only difference lies in their mode of origin. The alum

substance has been artificially prepared by the chemist, and the conditions necessary for its formation into crystals have been supplied by this very simple experiment. Minerals, on the other hand, have been formed in the earth's crust, and their crystals have grown under natural conditions without the intervention of man. Crystals of minerals we call for this reason natural crystals, as distinct from artificial crystals. It is to be borne in mind, however, that the latter are only artificial in so far as man has so controlled the conditions that crystals are capable of being formed; in other words, the crystal really makes itself when the conditions necessary for its growth are present.

We may then define a crystal as a body bounded on all sides by plane faces, and of such a form as is assumed by the substance itself.

In performing our experiment with alum, we will have noticed that the crystals were at first quite small, and that they gradually grew larger and larger. As the liquid cools or evaporates it is no longer capable of holding in solution so much alum, and this is then deposited on the growing crystals. All natural crystals of minerals have also grown in exactly the same manner; originally they were quite small, and they have reached their present size by slow growth during long periods of time.

Simple Crystal-forms and Combinations of Forms.

On closer inspection we see that all the faces of a crystal are not exactly alike. In the case of a crystal of quartz (fig. 1, plate 1), for example, it will be seen that the six faces of the column or prism are marked by horizontal lines, whilst the six faces forming the pointed end of the crystal are smooth and without such striations. Or again, on a crystal of mica the six surfaces at the edges of the plates are very rough, but the large face is perfectly smooth: it will also be noticed that the plates can be split up parallel to the large face only, and not to those at the edge. Numerous other examples of this kind might readily be given. For instance, the crystals of calcite represented in fig. 2, plate 1, consists of a six-sided prism with smooth and bright faces, terminated by a single face which is dull and white. The crystal of fluor-spar shown in fig. 3 of the same plate, consists of six bright faces perpendicular to one another, and of eight dull and rough faces with a triangular outline. That this difference in the surface markings of these two sets of faces on fluor-spar is not accidental, but is an essential character of the crystal, is proved by the fact that flakes may be split off the crystal parallel to the dull faces, but not parallel to the bright faces.

On the other hand, there exist also crystals bounded by faces which do not differ in surface characters. An excellent example of this is again afforded by fluor-spar. Fig. 4, plate 1, represents a crystal consisting of six bright faces perpendicular to one another, while the crystal shown in fig. 5 of the same plate is bounded by eight dull faces. From each of these eight faces of fluor-spar we can split off plates parallel to the faces, and all of them with the same degree of ease; the resulting form still consists of eight similar faces, but these are now bright and smooth, being in reality cleavage faces. A cleavage-form of fluor-spar obtained artificially in this way from a colourless crystal is shown in fig. 6, plate 1.

A crystal bounded by faces which are all alike, in the manner just explained, is said to represent a simple crystal-form (figs. 4, 5 and 6, plate 1). One which is

bounded by two sets of faces differing in character is said to be a combination of forms (fig. 2, 3 and 8).

Simple crystal-forms are distinguished by special names. For instance the eight-faced form of fluor-spar is called an octahedron, and the six-faced form a cube. The fluor-spar crystal first mentioned (fig. 3) is a combination of the cube and the octahedron. Other names for the simple crystal-forms will be given later on.

Character of Crystal-faces.

From what has just been said, we see that it is of some importance whether the faces of a crystal are bright or dull, striated or unstriated. Not only do these differences indicate whether the crystal is simple or a combination of forms, but they often tell us other secrets of the crystal. It is often said that the faces of a perfectly developed crystal should be absolutely plane and smooth. But such an ideally perfect crystal would show few of the surface features which help towards an elucidation of its internal structure. Nature avoids the ideally perfect, and even the lifeless crystals show individuality in their surface characters. As a matter of fact, however, perfectly smooth and bright faces do occur on some crystals, especially on those of small size; and they are then of special value to the crystallographer. But more often the faces are dull, drusy or striated. The faces of crystals of different minerals but of the same simple crystal-form often differ widely in character. For example, the faces of a cube of fluor-spar (fig. 4, plate 1) may be smooth; the faces of a cube of iron-pyrites (fig. 1, plate 26) are striated parallel to one edge; those of zinc-blende (fig. 4, plate 20) are striated parallel to one diagonal; those of galena (fig. 2, plate 16) parallel to both edges. In all these cases, although the form of the cube remains the same, there is an essential difference in the character of the crystals. Later we will have more to say as to the significance of these various markings on the faces of crystals.

The essential characters of Crystal-forms.

As yet we have considered the forms of crystals only so far as they are readily seen on a first inspection of minerals. It has been pointed out that different minerals have different forms of crystals. We must now inquire what constitutes the essential characters of crystals, and wherein lies the differences between crystals of different kinds. Clearly the actual size of a crystal is not a character of importance; for as we saw in our experiment with alum both small and large crystals were formed, and that the small ones gradually grew into large ones without any other change than that of their actual size. It is obvious also that the actual size of individual faces is of no essential importance, for this varies with the size of the crystal. The actual outline of the faces must also depend on the relative sizes of the neighbouring faces. If all the faces of a simple form are of the same size they will also have the same shape of outline, but this will not be the case when the faces differ in size. This may be seen from our crystals of alum. It is clear that the crystals, having all grown together, are essentially identical, but their actual shapes depend really on the position in which they have lain in the solution: the rate of growth may be hindered in certain directions by contact with other crystals or with the vessel containing the solution.

This same variation in the actual size of faces belonging to the same simple form is also well illustrated by cubes of transparent rock-salt. Plates may be split off the cube parallel to each of its faces, and with equal ease in all three directions. The resulting form is the cleavage-from of rock-salt. Now by splitting off plates of different thicknesses from different faces other cleavage forms differing widely from a geometrical cube may easily be obtained. As represented in the accompanying figures (fig. 3) the cleavage, form of rock-salt may be a true geometrical cube, or a long rectangular prism, or a rectangular plate. Of course, by further cleaving these latter forms to suitable amounts they may be reduced to true geometrical cubes. Now it is of the utmost importance clearly to understand that from a crystallographical point of view all these forms are in reality cubes. The difference between them depends only on the relative sizes and outlines of the faces, features which are quite accidental. In all cases the faces are perpendicular to one another, the angles between them being 90°, and they are all identical in their physical characters. The crystal-form as well as the cleavage-form of rock-salt is thus a simple cube, but owing to accidental causes the actual form may not be that of a regular geometrical cube.

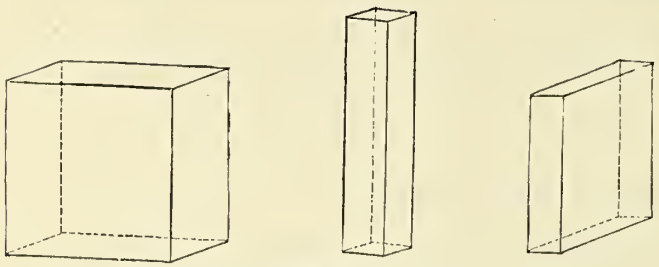

Fig. 3.
Cubic cleavage-forms of rock-salt.

Although the actual sizes and outlines of a crystal may vary without essential modification of the crystal, there can be no variation in the angles between the edges and between the faces. This we have already seen to be the case in the cleavage-forms of rock-salt. And, as a matter of fact, all crystals of the same kind of mineral have always the same angles between the faces, whilst in general for different minerals the angles will be different.

A rough but convincing proof of this fact can readily be demonstrated with the help of two crystals of quartz. If we place one of the crystals against the other in such a position that two striated faces are in contact and the striations on each parallel, we shall then see that corresponding to each face on the one crystal there is a similar face on the other crystal exactly parallel to the first; this could only happen if the angles between corresponding faces be identical in the two crystals. Again, if we place a rhomb-shaped cleavage plate of gypsum over a second such plate, it may readily be seen that both the obtuse and the acute angles are the same on both plates. The same will also be true of cleavage pieces of calcite when superimposed: when one pair of faces and edges are parallel all the remaining faces and edges of the two pieces will be exactly parallel, proving conclusively that the angles between the edges and faces of one piece are identical with the corresponding angles of the other piece. If, however, we place the cleavage piece of gypsum on the cleavage piece of calcite, the two may be turned about into all positions, but never will more than one face and one edge on each piece be simultaneously in parallel positions: this clearly results from the fact that angles of gypsum differ from those of calcite.

In the examples just given we have judged of the equality or difference of the angles by the eye alone, but when exact measurements of the angles of crystals are to be made a special instrument is used. Such an instrument is called a goniometer, or angle measurer, and the angles measured with it are the angles between the faces of the crystals. The construction of the more exact forms of this instrument is based on the

laws of reflection of light, and these are called reflecting goniometers. On such an instrument the angles of a good crystal with bright and smooth faces can be accurately determined to within a few seconds. A description of these instruments is given in the text-books on crystallography.

A more simple form of instrument, and one based on another principle, is that known as the contact goniometer, so called because portions of the instrument are laid in contact with the faces of the crystal to be measured. This form of instrument is especially useful for the measurement of large and rough crystals with which the reflecting goniometer is not applicable. A contact goniometer (fig. 4) is usually constructed of metal, and consists of a semicircular arc divided into 180°. An axis at the centre of the arc carries two bars, which may be clamped by means of a screw. One of these bars is fixed to the arc, but the other (the upper one in the figure) moves about the central axis over the graduated arc. In order to measure the angle included between any two faces of a crystal, for example, between the prism faces of the quartz crystal represented in fig. 9, plate 1, the fixed bar is first brought into contact with one face, and then the movable bar is turned round until it comes into contact with the second face. It is important to bear in mind that while this is being done the plane of the instrument must be perpendicular to the two faces, and this will be the case when the bars are perpendicular to the edge formed by the intersection of the two faces. The reading on the graduated arc will then give the angle between the two faces: in the figure the angle reading is 120°, this being the angle between the two faces of the crystal shown in fig. 9, plate 1.

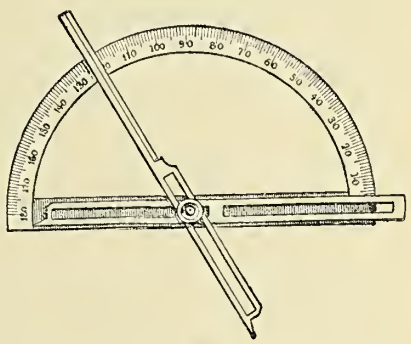

Fig. 4.
Contact goniometer.

By measuring the angles of a crystal with a goniometer in this way, it will be found that between corresponding faces on the same or on different crystals of the same mineral the angles are always identical. On quartz, for example, any pair of adjacent faces at the end of the crystal will always be found to be inclined at an angle of 133° 44′. On calcite two adjacent cleavage faces enclose an angle of 105° 4′, or the supplement of this, namely 74° 56′; and on a cleavage plate of gypsum the obtuse angle on the bright cleavage plane is 113° 46′. It is therefore possible by means of this measurement of angles to recognise the kind of mineral, and to distinguish different minerals one from another. It is also possible, when knowing the angle, to determine the forms of a crystal, in cases where the relations between them are obscured by irregularities of growth.

This constancy of the angles between corresponding faces of crystals of the same substance is of prime importance, and is in fact the fundamental law of the science of crystallography. The fact was first announced in 1669 by Nicolaus Steno, a Danish physician.

Distortion or Irregular Growth of Crystals.

From the example of the cleavage-form of rock-salt quoted above, we have seen that the faces, though identical in physical characters, may be very different in size; so that the cube may be bounded by large or small faces of varying shapes, but

always with a square or rectangular outline. A crystal on which all the faces with the same physical characters are developed of the same size is said to be an ideal crystal. In diagrams and models of crystals it is usual to represent the form with this ideal development, with similar faces all of the same size. In nature, however, such ideally perfect crystals are rarely if ever met with: usually the similar faces show small variations in size, and often this variation is very considerable. But in all cases the angles between the faces, whatever their size, are always the same.

The crystal of quartz (rock-crystal) represented in fig. 9, plate 2a, has the six faces of the prism of very nearly the same size, so that here we have a nearly ideally perfect hexagonal prism. The angle between two adjacent faces, measured over the vertical edges shown in the figure, is 120°. In the crystal of quartz shown in fig. 1 of the same plate the prism is much distorted; and, owing to the very large development of one pair of parallel faces and the small size of the four remaining faces, the crystal has the shape of a plate rather than of a prism. Here again, however, the faces are inclined to one another at the same angle of 120°, and they are marked by the same horizontal striations as on the more perfect crystal.

An almost ideally developed octahedron is shown in fig. 1 of plate 2; it is bounded by eight faces with the outlines of equilateral triangles which do not differ appreciably in size. The angle between any pair of adjacent faces of the octahedron is 109° 28′ 17″. Distorted octahedra are well represented in figs. 3 and 4, plate 29, where the faces though similar in physical characters differ greatly in size, but are inclined to each other at the same angle of 109° 28′ 17″.

The crystals shown on the plates accompanying this volume are represented with all their natural distortions and irregularities of growth. It will not be difficult, however, by an effort of the imagination to call up a picture of what the crystal in its ideal form would be. The latter are given as outline drawings in the text, and these should be compared with the plates.

The relations existing between the positions of the faces of a crystal.

The faces of a crystal are not distributed in a haphazard manner, but are arranged according to a definite plan. The existence of some plan in their arrangement becomes obvious when we note the directions of the edges between the faces of the crystal. It will be seen that for the same crystal the directions of the edges are fixed and unalterable. In the case of a quartz crystal (fig. 9, plate 1), for example, the edges between the striated prism faces and the smooth faces at the end of the crystal are parallel to the striations on the prism faces and perpendicular to the edges of the prism: when the prism faces are placed vertically, as in the figure, the edges in question will be horizontal. In the case of the fluor-spar crystal consisting of a combination of the cube and octahedron (fig. 3, plate 1), which we have already considered, the edges between these two sets of faces will be seen to be parallel to a diagonal of the cube faces. On the calcite crystals shown in fig. 2, plate 1, the dull face at the end is perpendicular to the smooth faces forming the prism.

It will also be noticed that the faces which together form a combination often intersect in parallel edges. For example, the small face shown at the upper left-hand side of the striated prism face of the quartz crystal in fig. 9, plate 1, intersects the two adjoining faces in edges which are parallel. Again in the quartz crystal shown in fig. 8

of the same plate the upper and lower edges of the prism faces are parallel: and all the six edges between the prism faces themselves are parallel to one another. Faces which intersect in parallel edges in this way are said to lie in a *zone* on the crystal; and by a zone is understood all those faces which would, if prolonged, intersect in parallel edges. For example, the six prism faces of quartz (fig. 8, plate 1) constitute a zone, since they intersect in parallel edges. Another zone on the same crystal is formed by a prism face and the terminal faces above and below it, and the corresponding faces on the other side of the crystal also lie in the same zone: on quartz crystals there are three such zones.

As a consequence of this arrangement of the faces of crystals in zones certain other relations between the faces will follow, and it is possible to express the positions of the faces by symbols or by numbers. For the latter purpose it is necessary to fix the position of certain faces and then find the relations of the other faces to those selected. There are various methods of doing this, and we will now describe one of the simplest which can be readily followed.

Consider that in the interior of a crystal we draw three straight lines intersecting at the centre. These lines are called the crystallographic axes, or simply axes; and they are chosen parallel to three edges, not all in the same plane, on the crystal. Any three lines might be arbitrarily chosen, but as we already have the edges in which the faces intersect in zones and we wish to find the relation existing between these edges and zones of faces, it will be far more convenient to choose such edges for axes. Next consider how each face on the crystal intersects these three axes; the ratios of their intersections on the axes will fix their relative positions.

With a cube of fluor-spar (fig. 4, plate 1) the axes most convenient to select are those parallel to the three edges of the cube (fig. 5). Since the three faces of the cube are similar, so must the three sets of edges in which the faces intersect be also similar to one another, and consequently the three axes must be all the same. We have therefore for the cube three axes at right angles to one another and of the same length; and each of these axes we may briefly indicate by the letter a. Consider now the relation of one of the faces of the cube with reference to this system of axes: it is intersected perpendicularly in its centre by one axis, and it is parallel to the other two axes, or in other words meets them at an infinite distance. The position of this face of the cube may then be expressed by the ratio of its intercepts on the three axes, namely $a : \infty a : \infty a$. And in the same way the other five faces of the cube will have the same symbol, which is thus the symbol for the whole form.

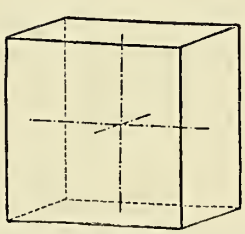

Fig. 5.
Cube with axes.

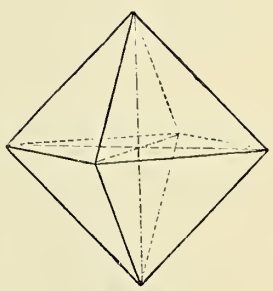

Fig. 6.
Octahedron with axes.

An octahedron face of fluor-spar (fig. 3, plate 1) intersects all three edges of the cube, and consequently it will intersect the three axes drawn parallel to the edges of the cube. Further, it may be seen that the face will cut the axes at equal lengths, since the edges between the cube and the octahedron faces are parallel to the diagonals of the cube faces. The same also easily follows from the fact that the octahedron face is equally inclined to the adjacent cube faces at equal angles. The position of the octahedron face is therefore given by the ratio of the axial intercepts $a : a : a$. This is

clearly the simplest ratio in which any face can intersect the three axes and the length a is therefore taken as unit length. The octahedron face is therefore taken as the unit face or parametral face, while the whole form composed of eight octahedral faces is spoken of as the primary form. This form is shown in fig. 6, where the axes are seen joining the opposite corners of the octahedron, and each face cuts all three axes at equal lengths. All other faces on a crystal will intersect the three axes in a ratio different from that of the primary form.

On cubes of fluor-spar, for example, there are sometimes six small faces on each of the eight corners of the cube (fig. 7). Each one of these small faces is obliquely inclined to the three edges of the cube, and therefore also to the axes; further it intersects the axes at different lengths, and its intercepts may be expressed generally by the ratio $a : ma : na$, where m and n are different whole numbers. The value of m and n which gives the lengths of the intercepts cannot be judged by the eye alone, but has to be calculated from the angles between the faces according to methods it is unnecessary to enter into here. In fig. 7 the values of m and n are 4 and 2 respectivly, so that the symbol of the small faces is $a : 4a : 2a$.

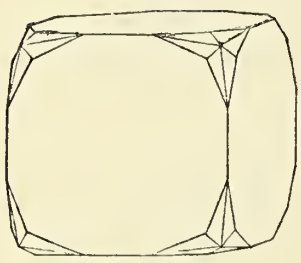

Fig. 7.
Cube in combination with hexakis-octahedron.

Now an important relation between the faces of crystals lies in the fact that in all cases the values of m and n can always be expressed by simple whole numbers or by simple fractions, such as 2, 3, 4, $^1/_2$, $^1/_3$, $^1/_4$, etc. They are never irrational numbers such as 1·27386... This law is know as the *rationality of intercepts*, and is one of the important laws of crystallography. It may be expressed as follows:

The faces of all crystals of any one substance are related to one another in such a manner that the ratio of their intercepts on the axes compared with the axial intercepts of the primary form can always be expressed by simple rational numbers.

The ratios of the intercepts on the axes of any face are known as the parametral ratios of that face; and the ratios of the intercepts of the primary face are called the axial ratios of the crystal. The simple rational numbers, which multiplied with the axial ratios give the parametral ratios of any particular face, are referred to as the indices of that face.

In this regularity in the distribution of the faces of a crystal lies the essential difference between crystals and other solid bodies bounded by plane faces, such as those artificially made by grinding. We recognise here again the influence of the force which has given origin to the crystal. In the same manner that chemical elements combine to form chemical compounds according to the law of multiple proportions, so also the faces of a crystal are related to those of the primary form in such a way that the axial intercepts of the one are simple multiples of those of the other. The structure of crystals thus conforms to laws of the utmost simplicity.

When, as in the octahedron, the three axes of the primary form are all of equal lengths the axial ratios may be expressed by the same letter, $a : a : a = 1 : 1 : 1$. When, however, the three axes of the primary form are of different lengths they have to be expressed by different letters, for example, $a : b : c$. The numbers which these letters represent can be calculated from the angles measured on the crystal, and they are irrational. For example, in aragonite the axial ratios are $a : b : c = 0{\cdot}6224 : 1 : 0{\cdot}7206$; that is the primary face cuts the three axes in lengths having these ratios. Any other face on a crystal of aragonite will have intercepts which are simple multiples of these numbers.

In many crystals the three crystallographic axes intersect at right angles, but in others this is not the case, and it is then necessary to determine the angles (α, β, γ) between the axes before the crystal can be completely determined.

In crystallographic descriptions it is usual to place one axis vertically, another from right to left, and the third directed towards the observer. The first is called the vertical axis, and the two others the lateral axes.

When the primary form of the crystals of a mineral is known, it is possible to determine the position of all the other faces on the same mineral by comparing their axial intercepts with those of the primary form. A notation serving this purpose was early devised by the mineralogist Christian Samuel Weiss; and this particular notation has an advantage over others in being readily comprehended.

Another system of notation is that proposed by C. F. Naumann, which has the advantage of brevity. Here the primary form is indicated by its initial letter; the regular octahedron by O, a pyramid by P, and a rhombohedron by R. For the other faces the numbers representing the multiple intercepts on the vertical axis are placed before these letters, and those for the lateral axis after the letters. The cube with the axial intercepts $a : \infty a : \infty a$ has therefore the Naumannian symbol $\infty O \infty$.

In a third system of notation known as the Millerian, since it was developed by W. H. Miller, the late Professor of Mineralogy at Cambridge, the intercepts of faces are given as fractional parts of the intercepts of the primary face, instead of as multiples thereof; thus

$$a : 2b : 4c \text{ becomes } \frac{a}{4} : \frac{b}{2} : \frac{c}{1},$$

and the symbol of the face is written as (421). These numbers (read four, two, one) are spoken of as the indices of the face. They refer to the intercepts on the a, b and c axes respectively; that is, the a axis is cut at one-fourth its length, the b axis at one-half, and the vertical c axis at its whole length. When a face is parallel to an axis, the corresponding index is zero, since $\frac{a}{0} = \infty a$.

The following examples will help to explain these symbols and indices:

$$a : a : a = \frac{a}{1} : \frac{a}{1} : \frac{a}{1} = 111$$

$$a : \infty a : \infty a = \frac{a}{1} : \frac{a}{0} : \frac{a}{0} = 100$$

$$a : 2a : 4a = \frac{a}{4} : \frac{a}{2} : \frac{a}{1} = 421.$$

The Millerian notation is the one most commonly used by crystallographers, since it readily adapts itself to calculations; but the Naumannian notation is perhaps easier to grasp when it is not intended, as in the present volume, to enter very far into crystallography. We will therefore here make use of the latter notation.

Crystal-Systems.

According to the number of their similar faces and to the frequency of repetition of the same angle between the faces, crystal-forms possess different degrees of regularity, or as it is better expressed, of symmetry. We have already seen that this is the case from the striations on the cube faces of crystals of different minerals. A smooth cube

face, as that in fig. 4, plate 1, can be divided by lines coincident with the two diagonals, or by lines parallel to each of the two edges, in such a manner that the one half is an exact repetition or mirror-reflection of the other half. On the other hand, a cube face which is striated parallel to one of its edges (fig. 6, plate 3) can only be symmetrically divided by lines parallel to and perpendicular to these striations, and not by lines following the diagonals of the face. A cube face which is striated parallel to one of its diagonals (fig. 2, plate 19) can be divided symmetrically by the two diagonals of the face, but not by lines parallel to the edges.

In the examples just given we have the symmetry of a face with respect to a line, but for the whole crystal the symmetry is with respect to a plane. We can imagine the crystal cut by a plane into two halves in such a manner that one half is the mirror-reflection of the other half. If one half be placed with its cut surface against a mirror we apparently see the whole crystal. A plane which in this way divides a crystal into two similar halves is called a *plane of symmetry*. The number of planes of symmetry possessed by any one crystal varies for different kinds of crystals, and according to their number we are able to distinguish different degrees of symmetry in crystals.

A cube with smooth faces will be seen to have nine planes of symmetry. The crystal may be divided into equal and similar halves by each of the three planes parallel to the faces of the cube; and it may also be symmetrically divided by each of six planes coincident with the diagonals of the cube and the diagonals of the faces, that is, parallel to the narrow faces in fig. 8. A cube which has its faces striated parallel to one edge can be symmetrically divided by only three planes, namely those parallel to the faces of the cube. Again, a cube with faces striated parallel to one diagonal is symmetrical with respect to the six planes passing though the diagonals. These three cubes thus differ not only in their surface characters, but also in the degrees of symmetry which they possess.

Nine planes of symmetry, as in the cube with smooth faces, is the greatest number possible in any crystal. Other crystals may have seven, six, five, four, three, two, one, or no planes of symmetry. The more important of the different types of symmetry are illustrated in figs. 8—13.

The crystal represented in fig. 9 has seven planes of symmetry; one is perpendicular to the prism faces, three more intersect in the edges of the prism and the pyramid, and the remaining three bisect the faces of the prism and of the pyramid; the first one being horizontal and the six others vertical in position. In fig. 10 there are five planes of symmetry: one horizontal and perpendicular to the prism faces lettered a and m; two vertical ones bisecting the faces s and m; and two vertical ones bisecting the faces a and e (in the figure those shown to the front and to the right). In fig. 11 the crystal possesses three planes of symmetry: one is horizontal through the horizontal edges between the pyramid planes P; the second is vertical passing through the front edges of P and over c; and the third, also vertical, passes through the faces n and c. The single plane of symmetry of the crystal in fig. 12 is vertical and bisects the faces c, a, r' and r. Finally the crystal represented in fig. 13 has no plane of symmetry.

Another kind of regularity in the distribution of the faces of a crystal is evident from the fact that two or more similar faces may be present about one edge or corner. If therefore the crystal be rotated about an axis passing through this edge or corner, these similar faces will be interchangeable in position. During a complete revolution of 360° about such an axis some crystals will occupy such a covering position only twice, others will do so three, four or six times. An axis about which a crystal may be

so rotated is called an *axis of symmetry*, and it may be two-, three-, four-, or six-fold in character. The crystal represented in fig. 11 possesses three axes of two-fold symmetry; the three similar faces meeting in a corner in fig. 8 are symmetrical about a three-fold axis; in fig. 10 there is one axis of four-fold symmetry; and in fig. 9 one of six-fold symmetry.

Finally, it will be seen with most crystals, which are completely bounded on all sides by faces, that corresponding to each face there is on the opposite side of the crystal, a parallel face similar in character to the first. Such crystals are said to possess a *centre of symmetry.*

In some crystals the only element of symmetry is a centre of symmetry; in others there may be one plane of symmetry, one axis of symmetry, and a centre of symmetry. The highest degree of symmetry possible in any crystal results from the

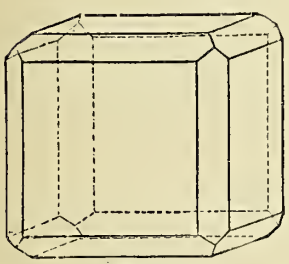

Fig. 8.
Crystal with 9 planes of symmetry.

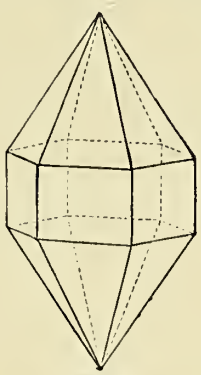

Fig. 9.
Crystal with 7 planes of symmetry.

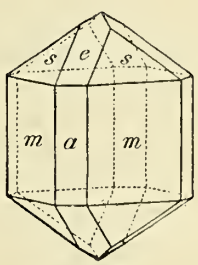

Fig. 10.
Crystal with 5 planes of symmetry.

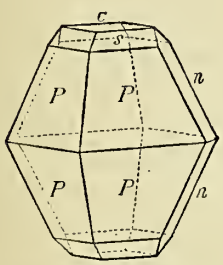

Fig. 11.
Crystal with 3 planes of symmetry.

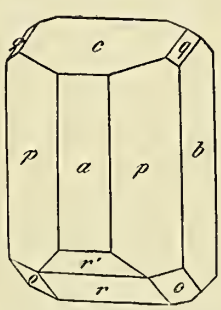

Fig. 12.
Crystal with one plane of symmetry.

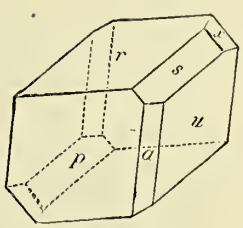

Fig. 13.
Crystal with no plane of symmetry.

association of nine planes of symmetry, thirteen axes of symmetry, and a centre of symmetry. Other crystals lie between these extremes in the degree of symmetry which they exhibit.

In this way all crystals may be divided into thirty-two classes, each having a different degree of symmetry. It is unnecessary in this place to enumerate these thirty-two classes of symmetry, since we do not wish to burden the reader with too many technical terms. All that we need give here are the six systems into which they may be grouped. These six systems may be defined by the lengths and mutual inclinations of the crystallographic axes.

1. *Cubic system.* — With three equal crystallographic axes (a, a, a) all at right angles to one another.

The highest degree of symmetry possible in this system in given by 9 ($= 3 + 6$) planes of symmetry, 13 ($= 3 + 4 + 6$) axes of symmetry, and the centre of symmetry.

2. *Hexagonal system.* — With three equal axes (a, a, a) lying in a horizontal plane at 60° to one another, and a fourth, vertical axis of different length (c) perpendicular to this plane. The highest possible symmetry is here, 7 ($= 1 + 3 + 3$) planes of symmetry, 7 ($= 1 + 3 + 3$) axes of symmetry, and the centre of symmetry.

3. *Tetragonal system.* — With two equal horizontal axes (a, a) and a vertical axis of different length (c), the three axes being perpendicular to one another.

The highest possible symmetry is here, 5 ($= 1 + 2 + 2$) planes of symmetry, 5 ($= 1 + 2 + 2$) axes of symmetry, and the centre of symmetry.

4. *Rhombic system.* — With three unequal axes (a, b, c) at right angles to one another.

The highest possible symmetry is, 3 ($= 1 + 1 + 1$) planes of symmetry, 3 ($= 1 + 1 + 1$) axes of symmetry, and the centre of symmetry.

5. *Monoclinic system.* — With three unequal axes (a, b, c), two of which (a, c) are inclined to each other at an oblique angle (β) and the third (b) is perpendicular to the first two.

The highest possible degree of symmetry is, 1 plane of symmetry, 1 axis of symmetry, and the centre of symmetry.

6. *Anorthic system.* — With three unequal axes (a, b, c) all inclined at oblique angles (α, β, γ).

The highest degree of symmetry possible in this system is only that given by the presence of a centre of symmetry.

Holohedrism and Hemihedrism.

Each of the six systems of crystals just enumerated embraces several classes of crystals differing from one another in their higher or lower degrees of symmetry, but all referable to a common type of axes. The crystals belonging to the several classes of the same system differ externally in the characters and number of their faces.

The simple form which possesses the highest degree of symmetry possible in each system is called the holohedral form of that system, since we have here the full number of faces that can be associated together with the particular arrangement of axes. The regular octahedron is, for example, a holohedral form, since it consists of eight faces each intersecting the axes in the ratios $a : a : a$, and no more are possible.

In other classes of the same system, in which the degree of symmetry is lower, the simple form may be developed with only half or one-quarter of the full number of faces. Such forms are called hemihedral (or half-faced) forms and tetartohedral (or quarter-faced) forms, respectively. They are related to the holohedral (or full faced) form according to definite rules; and the faces which are present have the same position on the crystal. The regular tetrahedron, for example, is a hemihedral form: it is related to the regular octahedron and can be derived from this by the omission of alternate faces of the octahedron. In a combination of forms the faces of the octahedron truncate all the corners of the cube, but the tetrahedron truncates only alternate corners. The tetrahedron is thus the hemihedral form of the octahedron.

In the present work, where we do not intend to enter very far into crystallography, it will be simpler to consider the holohedral, hemihedral and tetartohedral forms of each system rather than describe in detail the exact symmetry of each class.

All the crystals, to whatever mineral they belong, which fall into any one class possess the same degree of symmetry and have the same distribution of faces in

accordance with this type of symmetry. In certain cases it is possible that the form may have the same number of faces although belonging to different classes of the same system; and then it is only possible to recognise the lower or higher degree of symmetry by the surface characters of the faces or by the help of special physical characters.

The three regular cubes already mentioned (p. 18) have the same number of faces, but as shown by the characters of their faces they possess different degrees of symmetry. The smooth faced cube belongs to the holohedral class of the cubic system with nine planes of symmetry; the cube which has its faces striated parallel to one of the edges is hemihedral with three planes of symmetry; and the cube with faces striated parallel to one diagonal is hemihedral with six planes of symmetry.

Determination of the Symmetry of Crystals.

We have now learnt that the crystals of different systems and classes differ in the degree of symmetry which they possess, but how are we to recognise and to determine what the degree of symmetry is in each case?

We have already seen that this is possible to a certain extent by observing the number of the faces, their positions and their surface characters. In very many cases the symmetry of a crystal may be readily and correctly determined in this way, and the crystal may be assigned to one or other system or class. The three cubes of fluor-spar, iron-pyrites and zinc-blende, though identical in the number and positions of their faces, we have already determined by the aid of the characters of the faces. But suppose the faces had all been smooth and as far as we could judge by inspection the same in character, how are we to proceed?

In such a case there may really exist a difference, although it cannot be easily detected without the help of experiment. An experimental method which is here often of great help towards determining the symmetry of crystals consists in observing the effect of corrosion. If a crystal or a cleavage fragment of a crystal be placed in dilute acid or some other solution capable of slowly dissolving the material, it will be found that after a short time the faces of the crystal have become marked by a number of small pits or depressions. The surface markings so produced are called *etched figures* or corrosion figures, and they are often regularly and beautifully formed. In all cases they will exhibit the same degree of symmetry as that possessed by the face on which they occur. These etched figures are usually of only microscopical dimensions, but sometimes when produced naturally they are sufficiently large and distinct to be readily visible to the naked eye, for example, on the front prism face of the crystal of quartz shown in fig. 3 of plate 55. It will be noticed that these are set obliquely to the edges of the prism and that they are not symmetrical with respect to any line, either parallel to or perpendicular to the prism edges. From this it follows that neither a vertical nor a horizonal plane of symmetry is perpendicular to the prism planes of a crystal of quartz. But as far as can be judged from the crystal shown in fig. 8, plate 1, and in text-figure No. 9 quartz might possess both such planes of symmetry. The etched figures therefore prove that a quartz crystal really possesses a lower degree of symmetry than it apparently exhibits; and as a matter of fact quartz is hexagonal without any planes of symmetry.

Description of Crystal-forms.

In describing a simple crystal-form we will consider it to be ideally developed, having all the faces which are physically identical of the same size. We must then make out from the outlines of the faces and the angles between them what is the relation between the faces and their positions with respect to the crystallographic axes of reference. Sometimes with actual crystals this can be determined on a mere inspection of the crystal, but more often it is necessary to actually measure the angles between the faces.

In a combination we have to deal with two or more sets of faces which are physically different from each other and which may differ more or less considerably in size. The larger faces of the predominating form determine the habit of the crystal; and in describing a combination it is convenient to state how this predominating form is modified by the other forms which are present. Thus it is usual to say that a corner or edge is truncated (figs. 21, 22), an edge bevelled or replaced by two planes (fig. 23), or a corner replaced by two or more planes (fig. 24). We have already seen, for example, that the crystal shown in fig. 3, plate 1, is a combination, and it may be described as a form in which the cube predominates and in which the corners of the cube are truncated by the octahedron.

To which forms these smaller modifying faces belong can easily be made out, after a little practice, from their positions on the crystals or by determining their relations to the crystallographic axes.

Cubic System.

In crystals of the cubic system the three crystallographic axes are of equal lengths and are all at right angles to one another. We shall first consider the holohedral forms of the system, and afterwards the hemihedral forms which may be derived from them.

The holohedral forms possess nine planes of symmetry, three parallel to the cube faces, and six parallel to the faces of the rhombic-dodecahedron. In addition there are thirteen axes of symmetry and a centre of symmetry. The following seven different kinds of forms fall into this class.

1. *The octahedron* (fig. 14). This is identical with the regular octahedron of geometry, and is bounded by eight equilateral triangles, with angles of $109^0\ 28'\ 16''$ between the faces. The crystallographic axes join opposite corners of the figure, and the faces intersect these axes in the ratios $a : a : a$. The octahedron is therefore the primary form and is distinguished by the Naumannian symbol O. Examples, fluor-spar and magnetite.

2. *The cube* (fig. 15) is bounded by six similar faces at right angles to one another. The axes are parallel to the edges and intersect the faces in their centres. Each face is therefore parallel to two of the axes and cuts the third, and the ratios of the intercepts is $a : \infty a : \infty a = \infty O \infty$. Example, fluor-spar.

3. *The rhombic-dodecahedron* (fig. 16) is bounded by twelve rhomb-shaped faces. The angle between two adjacent faces which meet in an edge is 120^0. Each

face cuts two axes at equal lengths and is parallel to the third, and the symbol is therefore $a : a : \infty a = \infty O$. Example, garnet.

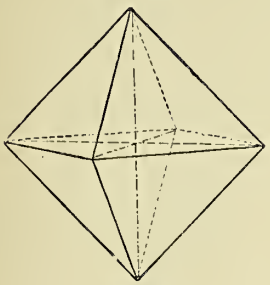

Fig. 14.
Octahedron.

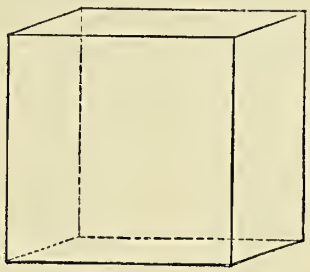

Fig. 15.
Cube.

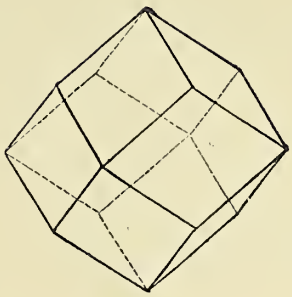

Fig. 16.
Rhombic-dodecahedron.

4. *A triakis-octahedron* or *three-faced octahedron* (fig. 17) bounded by twenty-four isosceles triangles, and resembling an octahedron with a triangular pyramid on each of its faces. Each face intersects two of the axes at equal lengths and the third at a greater distance from the centre; for example, $a : a : 2a = 2O$. This is rarely met with as a simple form.

5. *A tetrakis-hexahedron* or *four-faced cube* (fig. 18) bounded by twenty-four isosceles triangles, and resembling a cube with a square pyramid on each of its faces.

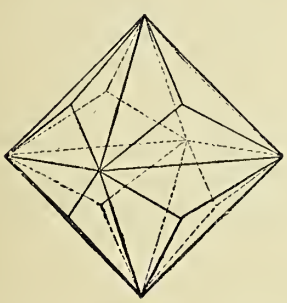

Fig. 17.
Triakis-octahedron or three-faced octahedron.

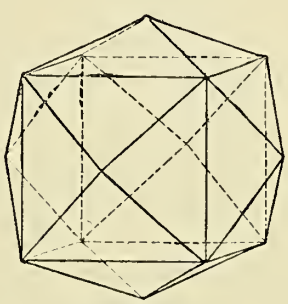

Fig. 18.
Tetrakis-hexahedron or four-faced cube.

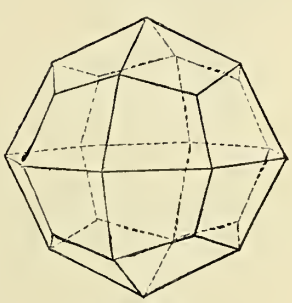

Fig. 19.
Icositetrahedron.

A face cuts two axes at different lengths and is parallel to the third; for example, $a : 2a : \infty a = \infty O 2$. Example, native copper (fig. 2, plate 10).

6. *An icositetrahedron* (fig. 19), bounded by twenty-four four-sided (deltoid) faces. Each face intersects two of the axes at equal lengths and the third axes at a shorter distance from the centre; for example, $2a : 2a : a = 2 O 2$. Example, analcite.

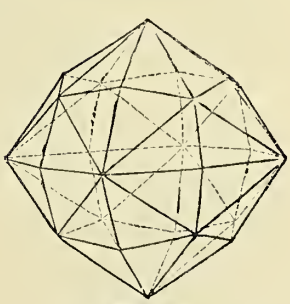

Fig. 20.
Hexakis-octahedron or six-faced octahedron.

7. *A hexakis-octahedron* or *six-faced octahedron* (fig. 20), bounded by forty-eight scalene triangles. A face intersects the axes in three different lengths; for example, $a : 2a : 4a = 4 O 2$. This is rare as a simple form.

Combinations of forms in holohedral cubic crystals.

Taking the *octahedron* as the predominating form of the combination, its corners are truncated by the cube (fig. 21), and its edges truncated by the rhombic-dodecahedron (fig. 22). The triakis-octahedron bevels the edges of the octahedron (fig. 23), and

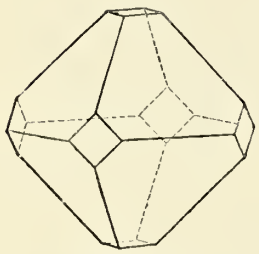

Fig. 21.
Octahedron with cube.

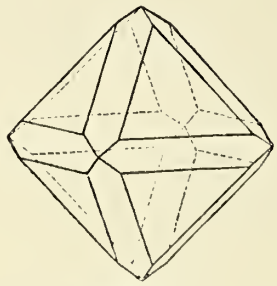

Fig. 22.
Octahedron
with rhombic-dodecahedron.

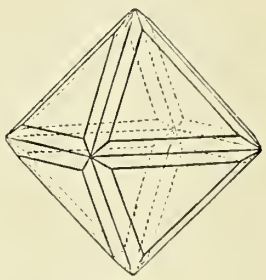

Fig. 23.
Octahedron
with triakis-octahedron.

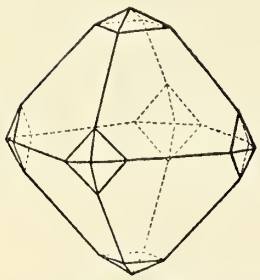

Fig. 24.
Octahedron with icositetrahedron.

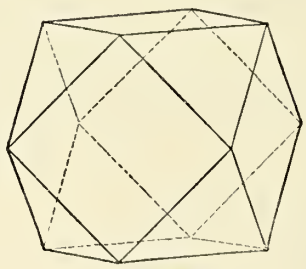

Fig. 26.
Cubo-octahedron.

the icositetrahedron replaces each of the corners by four faces (fig. 24).

It may happen that in a combination the faces of the different forms are developed to about the same extent as regards their size, and in such cases it cannot be said that either one or the other of the forms predominates. A case of this kind is illustrated in fig. 26, which is a combination of the octahedron and the cube in which neither predominates: this is called a cubo-octahedron.

When the *cube* predominates, its corners may be truncated by the octahedron (fig. 25), or its edges by the rhombic-dodecahedron (fig. 27). Its edges are bevelled by

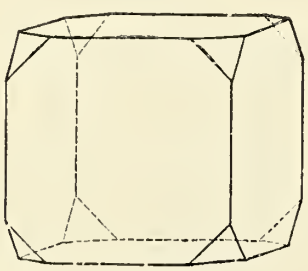

Fig. 25.
Cube with octahedron.

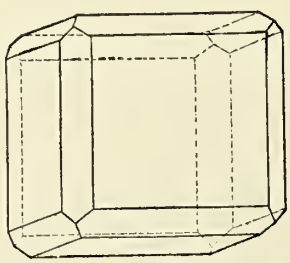

Fig. 27.
Cube with rhombic-dodecahedron.

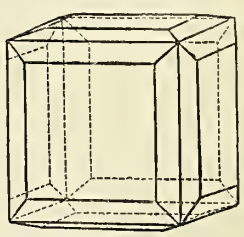

Fig. 28.
Cube with tetrakis-hexahedron.

the tetrakis-hexahedron (fig. 28); and its corners replaced by three faces by the icositetrahedron (fig. 29), or by six faces by the hexakis-octahedron (fig. 30).

With the *rhombic-dodecahedron* as the predominating form, its three-edged corners are truncated by the octahedron (fig. 31), and its four-edged corners are truncated by the cube. The icositetrahedron with the symbol $2\,O\,2$ truncates the edges (fig. 32), and the hexakis-octahedron $3\,O\,\frac{3}{2}$ bevels the edges (fig. 33): fig. 34 is a combination of

the rhombic-dodecahedron with both these forms, in which each edge is replaced by three faces.

Other combinations may occur, but they are of less importance.

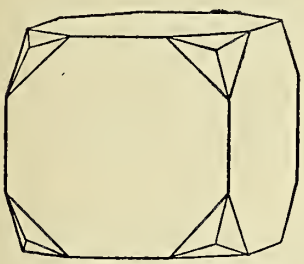

Fig. 29.
Cube with icositetrahedron.

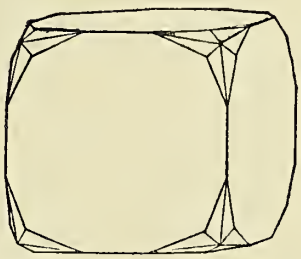

Fig. 30.
Cube with hexakis-octahedron.

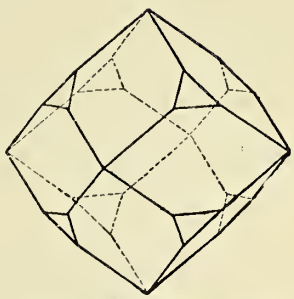

Fig. 31.
Rhombic-dodecahedron with octahedron.

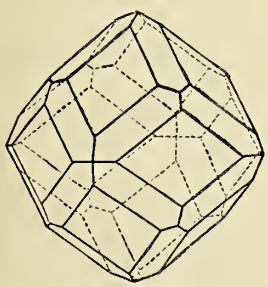

Fig. 32.
Rhombic-dodecahedron with icositetrahedron.

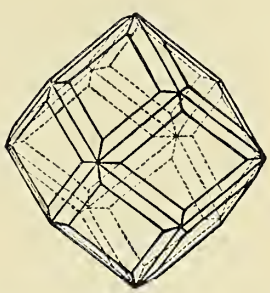

Fig. 33.
Rhombic-dodecahedron with hexakis-octahedron.

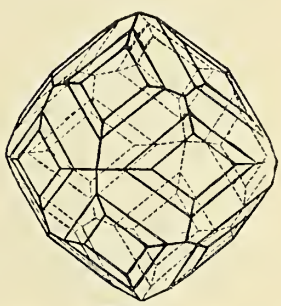

Fig. 34.
Rhombic dodecahedron with icositetrahedron and hexakis-octahedron.

Minerals which crystallize in this holohedral division of the cubic system are: gold, silver and copper; galena (plate 16), magnetite (plates 29 and 29a), garnet (plate 47), sodalite (plate 62), analcite (plate 63), rock-salt (plate 70) and fluor-spar (plate 71).

Tetrahedral Hemihedrism.

Some crystals of the cubic system may have a form closely resembling the octahedron, but with adjacent faces differing in character (fig. 35): for example, some

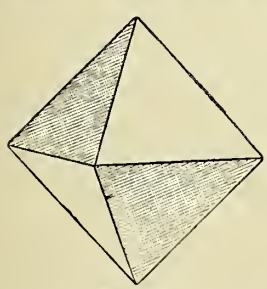

Fig. 35.
Octahedron with dissimilar faces (a combination of two tetrahedra).

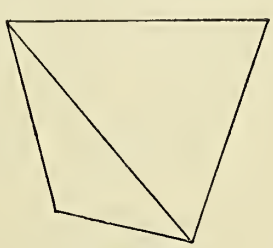

Fig. 36.
Tetrahedron.

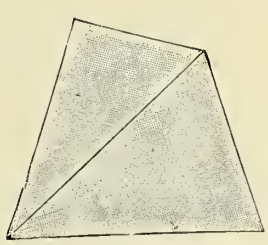

Fig. 37.
Complementary tetrahedron.

of the faces may be bright and smooth and the alternate ones dull and pitted, as in zinc-blende. When the faces differ also in size, as in a crystal of tetrahedrite (fig. 1,

plate 12), the difference in the form becomes more marked; and in certain cases the alternate faces may be altogether absent. We have then a new form, which is known as the *tetrahedron* (fig. 36), and may be considered as the half-form or hemihedral form of the octahedron. Naumann's symbol for the tetrahedron is therefore $\frac{O}{2}$. From an octahedron there can, of course, be derived two such half-forms, by the suppression of either one or other set of alternate faces. These two forms, the tetrahedron (fig. 36) and the complementary tetrahedron (fig. 37) are often distinguished respectively as the positive tetrahedron and the negative tetrahedron. In combination they give an octahedron (fig. 35).

In a similar manner, the hemihedral form of an icositetrahedron is a *triakis-tetrahedron* or three-faced tetrahedron, of which there are again two forms, a positive and a negative. Hemihedral forms may also be derived from the triakis-octahedron

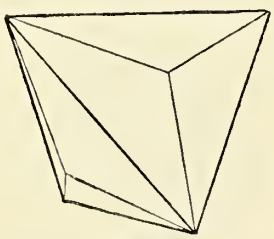

Fig. 38.
Triakis-tetrahedron or three-faced tetrahedron.

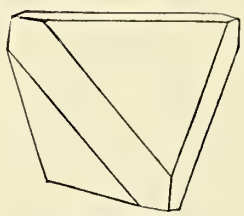

Fig. 39.
Tetrahedron with cube.

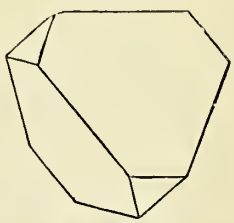

Fig. 40.
Tetrahedron with complementary tetrahedron.

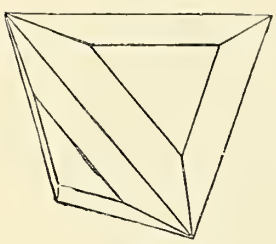

Fig. 41.
Tetrahedron with triakis-tetrahedron.

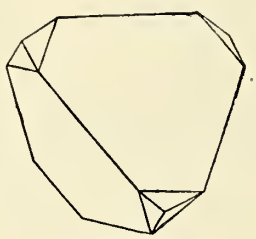

Fig. 42.
Tetrahedron with rhombic-dodecahedron.

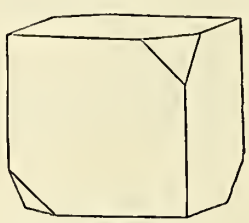

Fig. 43.
Cube with tetrahedron.

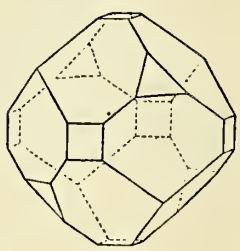

Fig. 44.
Rhombic-dodecahedron with cube and tetrahedron.

and the hexakis-octahedron, but these are of less importance. The cube, the rhombic-dodecahedron and the tetrakis-hexahedron remain unaltered in their external form, but they display a difference in character on their faces; for example, the faces of the cube of zinc-blende (plate 20, fig. 4) are striated parallel to only one of their diagonals.

Crystals of this hemihedral class of the cubic system posses only six planes of symmetry, namely those parallel to the faces of the rhombic-dodecahedron: the three planes of symmetry parallel to the cube-faces are here absent. These crystals may be distinguished by the fact that faces in alternate octants are similar in character, and differ from those in adjacent octants.

Combinations. — The tetrahedron has its edges truncated by the cube (fig. 39), and its corners truncated by the complementary tetrahedron (fig. 40). Its edges are bevelled by a triakis-tetrahedron of the same sign (that is in the same octant) (fig. 41), but a triakis-tetrahedron of opposite sign will replace the corners by three faces. In combination with the rhombic-dodecahedron the tetrahedron has each of its corners replaced by three faces (fig. 42).

The cube has alternate corners only truncated by the tetrahedron (fig. 43); and in the rhombic-dodecahedron the alternate three-edged corners are truncated (fig. 44). In this last figure the faces of the cube are present in addition to those of the rhombic-dodecahedron and the positive tetrahedron.

The best examples of this class of crystals are afforded by the minerals tetrahedrite (plate 12) and zinc-blende (plate 20).

Pentagonal Hemihedrism.

Iron-pyrites is frequently found as crystals which are bounded by twelve five-sided faces, and this form is called the pentagonal-dodecahedron (fig. 5 and 6 of plate 26, and text-figure 45). A face of this form intersects the crystallographic axes in the same

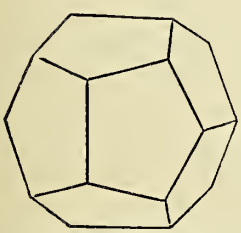

Fig. 45.
Pentagonal-dodecahedron.

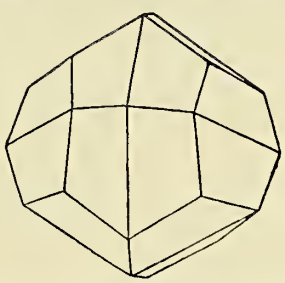

Fig. 46.
Dyakis-dodecahedron or diplohedron.

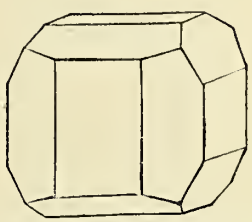

Fig. 47.
Cube with pentagonal-dodecahedron.

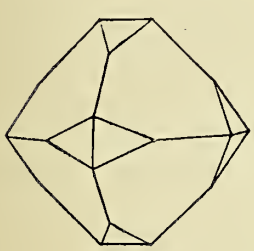

Fig. 48.
Octahedron with pentagonal-dodecahedron.

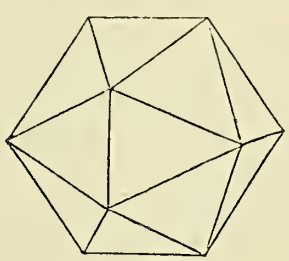

Fig. 49.
Octahedron and pentagonal-dodecahedron with faces of equal sizes.

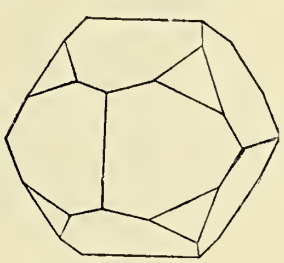

Fig. 50.
Pentagonal-dodecahedron with octahedron.

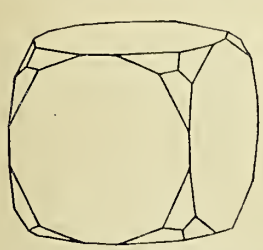

Fig. 51.
Cube with dyakis-dodecahedron.

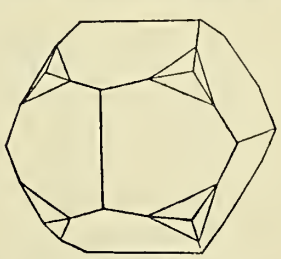

Fig. 52.
Pentagonal-dodecahedron with dyakis-dodecahedron.

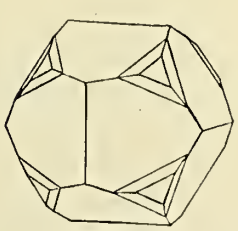

Fig. 53.
Pentagonal-dodecahedron with dyakis-dodecahedron and octahedron.

ratios as does a face of the tetrakis-hexahedron, which form is bounded by twenty-four faces. The pentagonal-dodecahedron is therefore a hemihedral form of the tetrakis-hexahedron, and its symbol may be written as $\frac{\backsim O2}{2}$.

Other crystals of iron-pyrites are bounded by twenty-four faces, which intersect the three axes in unequal lengths, $a : 3a : \frac{3}{2}a$. This form is then the hemihedral form of the hexakis-octahedron, which has twice the number of faces with the same intercepts; it is called the dyakis-dodecahedron or diplohedron (fig. 46), and it has the symbol $\left[\frac{3O\frac{3}{2}}{2}\right]$. This hemihedral form of the hexakis-octahedron is distinguished from the tetrahedral-hemihedral form with the same symbol by enclosing its symbol in square brackets.

The remaining forms, the octahedron, cube, etc., are the same in this hemihedral class as in the holohedral class of the cubic system; but their lower degree of symmetry is often indicated by the striations on the faces. For example, the cube of iron-pyrites is striated parallel to only one of its edges (plate 26, fig. 1).

Crystals of this class possess only three planes of symmetry, these being parallel to the faces of the cube. They may be distinguished from tetrahedral-hemihedral crystals by the fact that they have parallel faces; in the tetrahedral-hemihedral class similar faces are not parallel. Here also similar faces occur in adjacent octants.

Combinations. — The faces of the pentagonal-dodecahedron truncate obliquely the edges of the cube (fig. 47), and replace the corners of the octahedron by two faces (fig. 48). When the pentagonal-dodecahedron is the predominating form in combination with the octahedron, the latter truncates the three-edged corners of the former (fig. 50). In some crystals of iron-pyrites the faces of these two forms — the pentagonal-dodecahedron and the octahedron — are equal in size, and we then have a figure bounded by twenty ($= 12 + 8$) triangular faces (fig. 49): this is sometimes called an icosahedron, but it is distinct from the regular icosahedron of geometry, since its faces are not all similar and are not all equilateral triangles.

The dyakis-dodecahedron replaces each corner of the cube by three obliquely placed faces (fig. 51); it may also replace by three faces the three edged corners of the pentagonal-dodecahedron (fig. 52). Fig. 53 resembles the last combination with the addition of the octahedron.

Iron-pyrites (plate 26) and cobaltite (plate 36) furnish the best examples of minerals crystallizing in this class of the cubic system.

Tetragonal System.

Crystals of the tetragonal, or quadratic, system have similar characters in two directions at right angles to one another, but in the third direction, at right angles to the two similar directions, they have other characters. A cross-section of the crystal will as a rule be square in outline, and for this reason this system is sometimes called the quadratic. The three crystallographic axes are chosen in accordance with this development of the crystals: they are all at right angles, and two of them are equal, whilst the third has a greater or lesser length than the other two. The equal axes (a) are placed horizontally, and the third or principal axis (c) is placed vertically.

Crystals belonging to the holohedral class of this system have five planes of symmetry. One is perpendicular to the principal axis, and is called the horizontal or the principal plane of symmetry. The remaining four planes are vertical and all pass through the principal axis: two contain also the horizontal axes a, and the other pair

are inclined at 45° to these axes. In this class there are five kinds of forms, namely square pyramids and prisms, eight-sided pyramids and prisms, and the base. One of the square pyramids has to be chosen from the crystals of each kind of mineral to be the primary or fundamental pyramid with the axial intercepts $a : a : c$, and the symbol of the form is written as P. The positions of other forms on the same crystal are referred to this pyramid.

In this primary pyramid (fig. 54) the crystallographic axes join the opposite corners, and all other square pyramids whose faces intersect on the three axes in this way are called *pyramids of the first order.* According to whether these are steeper or lower pyramids, the faces intersect the vertical axis at a correspondingly greater or shorter distance from the centre than do the faces of the primary form. The symbols of such pyramids must then be $2P$, $3P$, or $\frac{1}{2}P$, $\frac{1}{4}P$, etc.

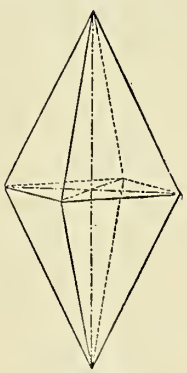

Fig. 54.
Tetragonal pyramid of the first order.

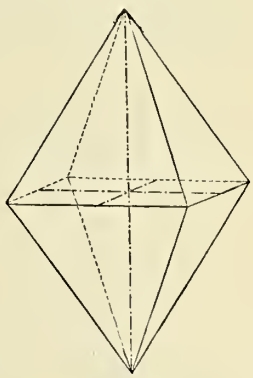

Fig. 55.
Tetragonal pyramid of the second order.

We may also have square pyramids whose faces intersect in only one of the horizontal a axes, and are parallel to the second (fig. 55); these are called *pyramids of the second order*, and they have the symbols $P\infty$, $2P\infty$, $\frac{1}{2}P\infty$, etc.

Corresponding with the pyramids of the first order we have the *prism of the first order* (fig. 56), which may be considered as a pyramid of such enormous steepness that it only intersects the vertical axis at an infinite distance (i. e., its faces are parallel to the vertical axis): the symbol is therefore ∞P. In the same way we have, associated with the pyramids of the second order, the *prism of the second order* (fig. 57), the faces of which are parallel to one of the horizontal axes and to the vertical axis: this form has the symbol $\infty P\infty$.

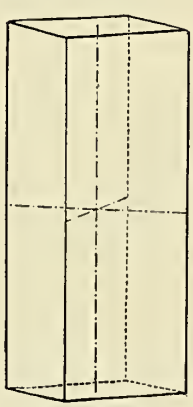

Fig. 56.
Tetragonal prism of the first order.

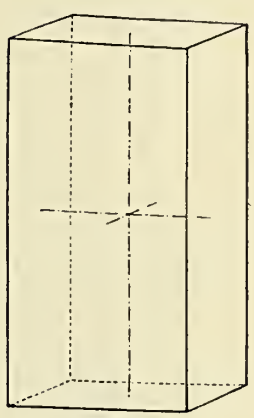

Fig. 57.
Tetragonal prism of the second order.

The faces of both these tetragonal prisms are inclined at 90°; and the cross-sections of the forms are square, as is also the case with the tetragonal pyramids of both orders. The forms of the first and second orders therefore do not differ from each other in their shape, but only with respect to their positions on the crystal; and it is only in combinations that they can be distinguished.

The *eight-sided pyramids and prisms* can readily be recognized by the number and positions of their faces. The faces cut the two horizontal axes in unequal lengths; the symbol $\infty P3$ for an eight-sided prism indicates that the intercept on one horizontal axis is three times as great as on the other. A common eight-sided pyramid has the symbol $3P3$.

The *base*, or basal pinacoid, consists of a pair of horizontal planes parallel to the a axes of the crystal, and, being like a very flat pyramid, has the symbol $0P$.

In *combinations* of these tetragonal forms, forms which are of the same order occur one above the other and intersect in parallel horizontal edges. If the forms are of different orders then one set of faces will truncate or replace the edges and corners of the other. Before we can determine all the forms of a combination, it is necessary to decide which is to be the primary pyramid: In fig. 58 the faces lettered *s* may be chosen as the primary pyramid *P*: the prism *m* will then be the prism of the first order, ∞P; the pyramid *e* truncating the edges of the first pyramid is a pyramid of the second order with the symbol $P\infty$; and *a* is the prism of the second order, $\infty P\infty$.

Fig. 59, representing a crystal of zircon is a combination of the primary pyramid *o*; another pyramid *s* also of the first order and with the symbol $3P$; the prism *M* of the first order; and the eight-sided pyramid *x*. The symbol of the last form is $3P3$, since each face intersects the axes in the ratios $a : 3a : 3c$, that is a face *x* intersects the vertical axis at three times the length that *o* intersects the same axis. This relation cannot be made out from a mere inspection of the crystal, but has to be calculated from the angles measured between the faces.

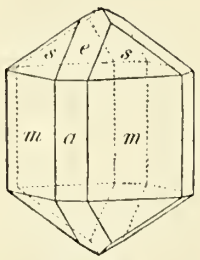

Fig. 58.
Tetragonal crystal (Cassiterite).

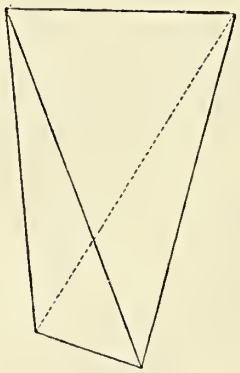
Fig. 60.
Tetragonal tetrahedron.

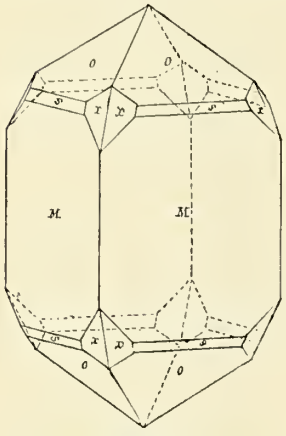

Fig. 59.
Tetragonal crystal (Zircon).

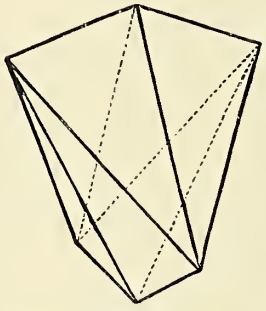
Fig. 61.
Tetragonal scalenohedron.

Examples of minerals crystallizing in this holohedral class of the tetragonal system are cassiterite (plate 38), rutile and anatase (plate 39), idocrase (plate 49) and phosgenite (plate 17).

There are several hemihedral and tetartohedral classes of the tetragonal system, but in this place mention need only be made of one of the most important. This is the *tetrahedral-hemihedral* class, corresponding to the tetrahedral-hemihedral class of the cubic system. From a tetragonal pyramid two tetragonal tetrahedra (fig. 60) may be derived, just as two regular tetrahedra are derived from the octahedron. These forms each consist of four equal isosceles triangles, and have the symbols $+\frac{P}{2}$ and $-\frac{P}{2}$. From an eight-sided tetragonal pyramid two so-called tetragonal scalenohedra (fig. 61) may be derived. Hemihedral forms of this kind are met with in copper-pyrites (plate 11).

Hexagonal System.

Holohedral crystals of the hexagonal system have a sixfold arrangement of their faces, and cross-sections of simple forms will be regular hexagons. Corresponding to this type of symmetry we must select for crystallographic axes three equal axes

(*a*) lying in the horizontal plane and with angles of 60° between them, and a fourth vertical axis (*c*) of a length different to the other three: the latter is called the principal axis and it is an axis of hexad symmetry.

These crystals possess seven planes of symmetry. One of them is perpendicular to the principal axis and therefore horizontal. The six others are vertical and contain the vertical axis; they are arranged in two sets of three, those of one set being parallel to, and those of the other set perpendicular to, the horizontal crystallographic axes.

As in the tetragonal system, there are also here five types of simple forms, but the faces are in sets of six instead of four. These simple forms are the hexagonal pyramids and prisms, the twelve-sided pyramids and prisms, and the base. One of the hexagonal pyramids has to be selected as the primary pyramid for each mineral which crystallizes in this system. The four crystallographic axes join opposite corners of this pyramid (fig. 62) of which the symbol is written P. Other forms are referred to the same system of axes and their relation to the primitive form determined, just as in the tetragonal system.

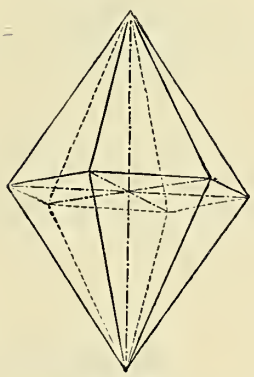

Fig. 62.
Hexagonal pyramid of the first order.

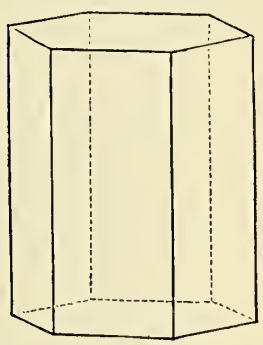

Fig. 63.
Hexagonal prism of the first order.

Pyramids of the first order are those in which the axes join opposite corners; the symbols are P, $2P$, $\frac{1}{2}P$, etc.

Pyramids of the second order have one of the horizontal axes passing through the centre of each of their horizontal edges, the two other horizontal axes being intercepted at twice the distance. The symbols are therefore $P2$, $2P2$, etc.

Pyramids of the two orders do not differ in form, but only in the lie of their faces with respect to the crystallographic axes; and it is only in combinations that they can be distinguished.

Corresponding to each of these two orders of pyramids there are also hexagonal prisms with faces parallel to the vertical axis, and angles of 120° between the faces.

The *prism of the first order* has the axes passing through the edges of the prism, and the symbol is ∞P. The hexagonal prism shown in fig. 63 is placed in a position corresponding to the pyramid in fig. 62, and is therefore the prism of the first order.

The *prism of the second order* has the symbol $\infty P2$; here the axes pass out through the centres of the faces. Drawn in the position adopted for the accompanying figures, there will be an edge of this prism directed towards the observer; this may be seen from a comparison of figs. 70 and 71, in which the two prisms are of the first and second orders respectively.

The *twelve-sided pyramids and prisms* are easily recognized by the number and positions of their faces. The faces intersect in unequal lengths on the horizontal axes. The commonest twelve-sided pyramid is that with the symbol $3P\frac{3}{2}$, and the corresponding prism is $\infty P\frac{3}{2}$.

The *base*, or basal pinacoid, consists of a pair of parallel faces placed at opposite ends of the crystal, and, like the prisms, can only exist in combinations. The symbol is 0 *P*.

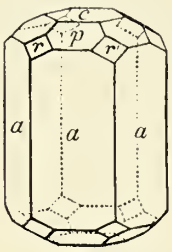

Fig. 64.
Hexagonal crystal
(Beryl).

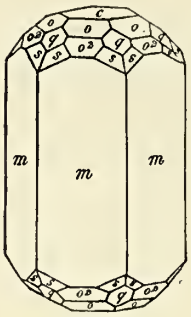

Fig. 65.
Hexagonal crystal
(Beryl).

In *combinations*, forms of the same order lie one above the other, whilst forms of different orders truncate or replace the edges and corners of each other.

In fig. 64, the faces *p* are chosen as belonging to the primary pyramid; *a* is then the prism of the first order, *r* a pyramid of the second order, and *c* the base. The symbols are *P*, ∞P, 2 *P* 2, 0 *P*.

In fig. 65, taking *o* as the primary pyramid *P*, o^2 is then a steeper pyramid 2 *P* of the same order, *m* the prism of the first order ∞P, *q* a pyramid of the second order 2 *P* 2, *s* a twelve-sided pyramid $3P\frac{3}{2}$, and *c* the base.

To this holohedral class of the hexagonal system the mineral beryl belongs (plate 44, and text-figs. 64 and 65).

Hemihedral forms.

Very few minerals crystallize in the holohedral class of the hexagonal system, but there are several important minerals which crystallize in hemihedral or tetartohedral classes of this system. The lower degree of symmetry characteristic of these classes is not, however, always obvious. The crystals of amethyst represented in plate 56, figs. 1 and 4 are, for example, apparently a combination of a hexagonal prism with a hexagonal pyramid. Here it must be pointed out that the apparent hexagonal pyramid is really a combination of two forms: this may be seen in fig. 2 of the same plate, where three of the faces are bright and smooth and the three others alternating with the first three are quite rough. Or again in fig. 3, the three alternate faces of one set are large, whilst the other three are small; in fig. 5 these latter faces are still smaller, and in certain cases they may be completely absent. We then have the crystal terminated by only three faces, and at the other end of a completely developed crystal there would be three faces each parallel to those at the top. A simple form derived in this way by suppressing alternate faces of a doubly terminated hexagonal pyramid is know as a *rhombohedron*. And the type of hemihedrism is called *rhombohedral hemihedrism*. A rhombohedron (fig. 66) is bounded by six similar rhomb-shaped faces, opposite pairs of which are parallel. The form can readily be obtained by breaking up any crystal of calcite, since this mineral splits with ease along three plane directions parallel to the faces of a rhombohedron. Over the six edges (three at each end) which intersect in the vertical axis of the crystal the angles between the faces are obtuse, but over the other six zig-zag edges around the equatorial portion of the crystal the angles are acute. The three horizontal crystallographic axes pass out at the centres of these zig-zag edges.

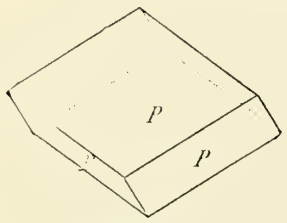

Fig. 66.
Rhombohedron.

For the reason that far more minerals crystallize as rhombohedra than as hexagonal pyramids, Naumann gave a special symbol (R) to that rhombohedron which may be selected as the primary rhombohedron: in calcite the cleavage rhombohedron is selected. Now, there may be two sets of rhombohedra: those which have their faces turned the same direction as the primitive rhombohedron, or in other words are of the same order, are called positive rhombohedra, e. g., $+4R$, $+\frac{1}{4}R$, etc.; and those of the second order truncating the edges or corners of the first order, which are called negative rhombohedra, e. g., $-2R$, $-\frac{1}{2}R$, etc. In the figures here given the positive rhombohedra are drawn with an upper face towards the observer (fig. 66), and the negative rhombohedra with an upper edge (fig. 67) towards the observer.

It will now be clear that the three larger and brighter terminal faces forming the apparent hexagonal pyramid of amethyst (plate 56) belong to a rhombohedron which we may call $+R$, and that the three smaller and dull faces belong to the negative rhombohedron $-R$.

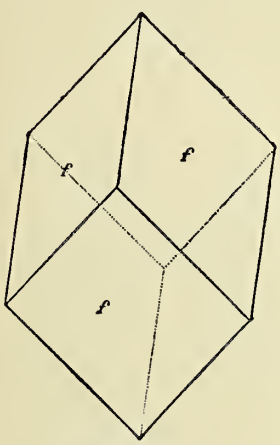

Fig. 67.
Rhombohedron.

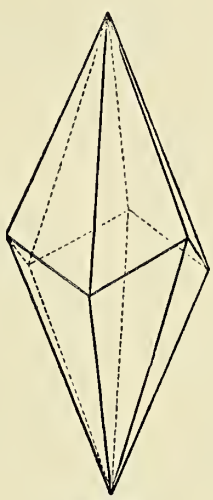

Fig. 68.
Scalenohedron.

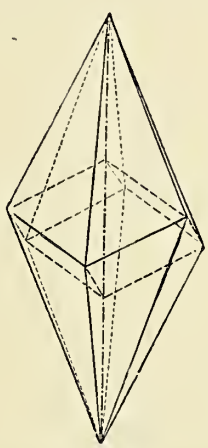

Fig. 69.
Scalenohedron with enclosed rhombohedron.

In this hemihedral class there is, besides the rhombohedron, an important form known as the *scalenohedron* (fig. 68). This may be derived from the twelve-sided hexagonal double pyramid by suppressing alternate faces. In this form there is also a threefold arrangement of the faces about the vertical or principal axis, which is an axis of threefold or trigonal symmetry. The form is bounded by twelve similar faces, or six pairs of parallel faces, with the form of scalene triangles. There are thus three sets of edges, and the angles between the faces are different over the dissimilar edges. The six edges meeting the vertical axis at the top and the six meeting it below are alternately longer and shorter, and the angles over them are alternately obtuse and acute. The six median edges forming a zig-zag belt round the crystal coincide with the corresponding edges of a rhombohedron, as shown in fig. 69. This figure represents a scalenohedron with the primary rhombohedron drawn inside; and it may be seen by placing a rule over the figure that the steeper faces of the scalenohedron intersect the vertical axis at three times the distance that the rhombohedral faces intersect the same axis. The intercepts on the horizontal axes are the same; so that the scalenohedron represented in fig. 69 has the symbol $R\,3$. Each rhombohedron, whether positive or negative, may have scalenohedra associated with it in this way: for example, with

the negative rhombohedron $-2R$ there may be the negative scalenohedra $-2R2$, $-2R3$, etc.

In this type of hemihedrism it is only the hexagonal pyramids of the first order and the twelve-sided pyramids of the hexagonal system which have the number of their faces reduced. The hexagonal pyramids of the second order still remain as such with the symbols $P2$, $2P2$, etc. The hexagonal prism of the second order is given the symbol $\infty P2$; but the hexagonal prism of the first order and the base are now referred to as ∞R and $0R$ respectively, since they may be considered as very steep or very flat rhombohedra.

Combinations. — Combinations of a rhombohedron with a hexagonal prism differ in appearance according to whether the prism is of the first or of the second order. Fig. 70 shows a combination of a negative rhombohedron $-\frac{1}{2}R$ with the prism of the first order ∞R: here the faces of the rhombohedron lie respectively above and below alternate faces of the prism. Fig. 71 shows a combination of a positive rhombohedron R with the prism of the second order $\infty P2$: here the faces of the rhombohedron lie opposite the edges of the prism, and on the crystal there are three zones, each

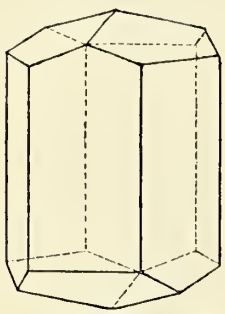

Fig. 70.
Prism of first order with rhombohedron.

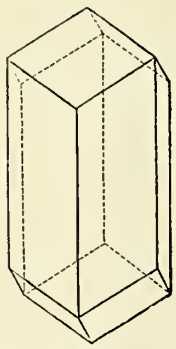

Fig. 71.
Prism of second order with rhombohedron.

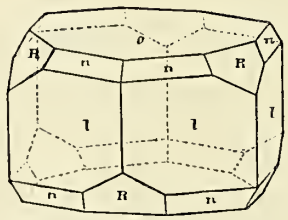

Fig. 72.
Prism and pyramid of second order with rhombohedron and base (Corundum).

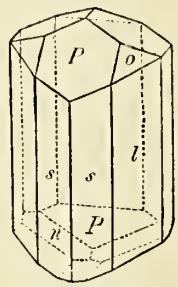

Fig. 73.
Hemimorphic-rhombohedral crystal (Tourmaline).

containing four rhombohedron faces and two prism faces. (Another zone on this crystal is that of the six prism faces.) A combination of a negative rhombohedron with the prism of the second order shows also the same relations.

Fig. 72 is a combination of the primary rhombohedron R, the prism l of the second order, a hexagonal pyramid n also of the second order, and the base o.

Combinations of positive and negative rhombohedra are of frequent occurrence, and often the faces of one truncate the edges of the other. When the latter is the case, the truncating rhombohedron has half the intercept on the vertical axis that the truncated rhombohedron has: thus the rhombohedron $-\frac{1}{2}R$ truncates the edges of R, R truncates the edges of $-2R$, and $-2R$ truncates $+4R$, etc. The scalenohedron also frequently occurs in combinations. The best examples are given by crystals of calcite (plates 72 and 73). Other minerals which crystallize in this class are corundum (plate 42) and haematite (plate 28).

Some of the other classes of the hexagonal system must be briefly mentioned here, since they are especially characteristic of certain minerals: these are illustrated in the next five figures.

Fig. 73 shows a characteristic form of tourmaline crystal, in which the three-fold symmetry about the vertical axis is apparent, but here the crystal is bounded at

the two ends by faces of different forms and these faces are not parallel. Crystals which are differently developed in this manner at their two ends are said to be hemimorphic. And the class to which tourmaline belongs is called the *rhombohedral-hemimorphic:* it may be considered as a hemihedral form of the rhombohedral class or as a tetartohedral form of the holohedral hexagonal class. The rhombohedra here become triangular pyramids with only one end, that is, they are not doubly terminated like the hexagonal pyramids of the holohedral class. In the figure the three faces P at the top form such a triangular pyramid, which may be taken as the primary form with the symbol $+R$: the faces o will then be $-2R$ since the edges between them are truncated by the faces P. At the other end of the crystal there is a second pyramid P also with the symbol $+R$ (the combination of these two together would give a rhombohedron) with the pyramid $-\frac{1}{2}R$. The three faces of the prism l belong to those of the prism of the first order ∞R; whilst the six faces of the prism s are those of the second order, which is not affected by the hemimorphism. Crystals of tourmaline which have grown with one end attached to their rocky matrix will not, of course, show this different development at the two ends, but they will still show the faces of the triangular prism of the first order: and this triangular outline of the prisms of tourmaline is an especially characteristic feature of the mineral.

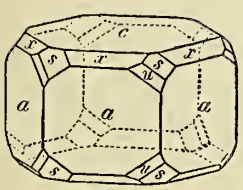

Fig. 74.
Pyramidal-hemihedrism (Apatite).

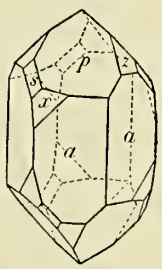

Fig. 75.
Trapezohedral-tetartohedrism (Quartz).

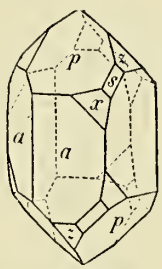

Fig. 76.

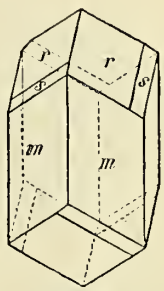

Fig. 77.
Rhombohedral-tetartohedrism (Dioptase).

Fig. 74 represents a crystal of apatite (see also plate 81, fig. 2), which belongs to the *pyramidal-hemihedral* class of the hexagonal system. Here there is a sixfold symmetry or repetition of the faces around the vertical axis. The crystal is a combination of the base $c = 0P$, a hexagonal pyramid of the first order $x = P$, a hexagonal pyramid of the second order $s = 2P2$, and the hexagonal pyramid u. The faces of the last form have the same positions as half of the faces of the twelve-sided double pyramid (s in fig. 65) $3P\frac{3}{2}$ of the holohedral class: their symbol is therefore written as $\frac{3P\frac{3}{2}}{2}$.

Figs. 75 and 76 represent crystals of quartz, in which p is the rhombohedron $+R$ and z the rhombohedron $-R$, the two together being equivalent to a hexagonal pyramid of the first order. The prism faces a belong to the hexagonal prism of the first order. In addition there are the small faces s and x placed on alternate corners between the rhombohedron and prism faces. The six faces s belong to a double triangular pyramid derived from a hexagonal pyramid of the second order (as in fig. 74) by the omission of half of the faces: those of x, also six in number, have the positions of one-quarter of the faces of a twelve-sided double pyramid of twenty-four faces. These six faces x would in a simple form give a figure which is called a

trapezohedron; and, as this is a quarter-faced or tetartohedral form of the twelve-sided double pyramid, this type of crystal belongs the trapezohedral-tetartohedral class of the hexagonal system. In fig. 75 the trapezoidal faces x lie to the left of p, and in fig. 76 to the right: we must therefore distinguish two kinds of quartz crystals respectively as right-handed and as left-handed crystals. These are related to one another in the same manner as the right hand to the left hand, one being the mirror-reflection of the other: they cannot be brought into coincident positions. Such pairs of crystals are said to be enantiomorphous.

In Fig. 77, representing a crystal of dioptase, r is again the primary rhombohedron $+R$, and m is the hexagonal prism of the second order (compare fig. 71). In addition we have the faces s of another rhombohedron placed on alternate edges between the faces of r and m. If there were similar faces on all the edges between r and m the form would be a scalenohedron: this form is therefore a hemihedral form of the scalenohedral, and consequently a tetartohedral form of the twelve-sided double pyramid. This class of tetartohedrism is therefore called rhombohedral-tetartohedrism.

Rhombic System.

Crystals of the rhombic system may be referred to a set of crystallographic axes which are all at right angles to one another, but are all of unequal lengths. The vertical axis is denoted by the letter $\dot{c}$. The longer of the two horizontal axes is placed from right to left and is called the macro-diagonal or macro-axis; this is lettered $\bar{b}$. The shorter horizontal axis is directed towards the observer, and is called the brachy-diagonal or brachy-axis, with the letter $\breve{a}$. In the holohedral class of this

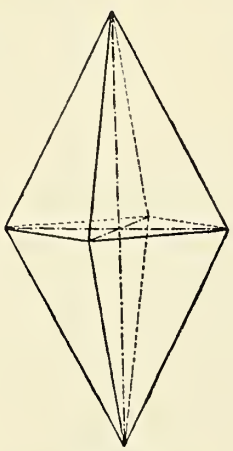

Fig. 78.
Rhombic pyramid.

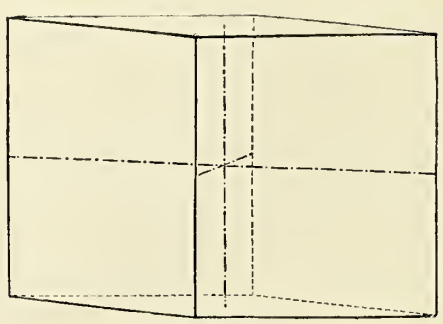

Fig. 79.
Rhombic prism.

system there are three planes of symmetry, which are at right angles to each other. There are only three different kinds of forms; namely, pyramids, prisms and pinacoids. A cross-section of the two first of these forms is a rhomb; hence the name of the system.

Rhombic pyramids (fig. 78) are bounded by eight similar triangular faces with unequal sides. The faces cut the three axes at unequal lengths, the primary pyramid P cutting them in the ratio $a:b:c$. Lower pyramids will have the symbols $\frac{1}{2}P$, $\frac{1}{3}P$, etc.,

and steeper pyramids the symbols 2 P, 3 P, etc. Other pyramids may cut the horizontal axes at distances which are multiples or sub-multiples of a or b; and their symbols may be $P\breve{2}$, $P\bar{2}$ etc., according as the a or b axis is cut at a different length.

Rhombic prisms consist of four faces parallel to one or other of the three axes. When the faces are parallel to the vertical axis the form is called a vertical prism (fig. 79) with the symbol ∞P, $\infty P\breve{2}$, $\infty P\bar{2}$, etc., according to the intercepts of the faces on the two horizontal axes. A set of four faces parallel to the $\breve{a}$ axis is called a brachy-prism or a brachy-dome, since the two upper sloping faces are like the roof of a house: here the symbols may be $P\breve{\infty}$, $\frac{1}{2}P\breve{\infty}$, etc. When the four faces are parallel to the $\bar{b}$ axis, the form is called a macro-prism or macro-dome, and the symbols are $P\bar{\infty}$, $2\,P\bar{\infty}$, etc. The form $P\bar{\infty}$ for instance intercepts the $\bar{b}$ axis at an infinite distance and the other two axes $\breve{a}$ and $\dot{c}$ at the same distances as the primary pyramid: the form $2\,P\bar{\infty}$ intercepts the vertical axis at twice the length c.

The *pinacoids*, or end faces, consist of a pair of parallel faces on opposite sides of the crystal and parallel to two of the axes. That pair parallel to the vertical axis and the macro-axis $\bar{b}$ is called the macro-pinacoid, with the symbol $\infty P\bar{\infty}$; and the other vertical pair parallel to the brachy-axis $\breve{a}$ is the brachy-pinacoid, with the symbol $\infty P\breve{\infty}$. The third pinacoid with horizontal faces parallel to the two horizontal axes is called the basal pinacoid or base, and has the symbol 0 P.

Combinations of forms in rhombic crystals can readily be made out after it has been decided which of the three axes is to be the vertical axis, and which pyramid is to be the primary pyramid.

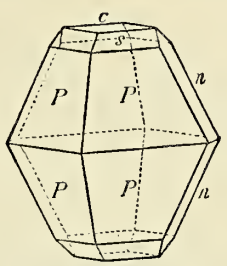

Fig. 80.
Rhombic crystal (Sulphur).

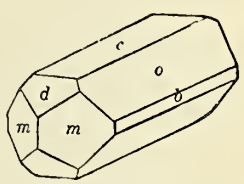

Fig. 81.
Rhombic crystal (Celestite).

In the crystal of native sulphur represented in fig. 80, the set of eight large faces P may be taken as the primary pyramid P; s is then a flatter pyramid of which the symbol is $\frac{1}{3}P$; n is a brachy-dome $P\breve{\infty}$; and c the base 0 P. In fig. 81, representing a crystal of celestite, no pyramid faces are present: m may be taken as the vertical prism ∞P; b is then the brachy-pinacoid $\infty P\breve{\infty}$, o the brachy-dome $P\breve{\infty}$, d the macro-dome $\frac{1}{2}P\bar{\infty}$, and c the base 0 P.

Several minerals crystallize in this holohedral class of the rhombic system: for example, barytes and celestite (plates 76—78), aragonite (plate 74), topaz (plate 46), sulphur (plate 25), stibnite (plate 23), atacamite (plate 14). Hemihedral forms are of less importance.

Monoclinic System.

Crystals of this class may be readily distinguished by the fact that they possess only a single plane of symmetry. Of the three crystallographic axes only one is fixed in position with respect to the symmetry of the crystal: this being the axis perpendicular to the plane of symmetry, which is called by Naumann the ortho-axis $\bar{b}$, and is placed horizontally from right to left. The other two crystallographic axes lie in the plane of symmetry, and are arbitrarily chosen parallel to any prominent or convenient edges of the crystal. These are, of course, both perpendicular to the ortho-

axis, but are inclined to one another at an oblique angle (β). One of them is placed in a vertical position and marked $\dot{c}$; the other will then be directed towards the observer in a sloping position, and is therefore called the clino-axis $\dot{a}$. The crystal is also so placed that the larger (obtuse) of the two oblique angles β is to the front and above. The three axes $\dot{a}$, $\bar{b}$ and $\dot{c}$ being of different characters, will also be of different lengths. The different faces on a monoclinic crystal are defined by their positions with respect to these axes.

Pyramids are forms whose faces intersect all three axes; they consist of only four faces (two pairs of parallel faces) which intersect each other in parallel edges, like the prisms of the rhombic system. For this reason they are more properly called hemi-pyramids. Naumann again gives the symbol P to such forms, distinguishing between those which lie to the front or to the back of the crystal as $-P$ and $+P$ respectively.

Clino-domes, or clino-prisms, also consist of a set of four faces intersecting in parallel edges and with a rhombic cross-section. These are arranged parallel to the clino-axis, and have the symbols $P\dot{\infty}$, $2P\dot{\infty}$, etc.

Ortho-domes, or ortho-prisms, are again the same, but are parallel to the ortho-axis $\bar{b}$. The symbols are $-P\bar{\infty}$ or $+P\bar{\infty}$ according to whether they are at the front or the back of the crystal; or $-\frac{1}{2}P\bar{\infty}$, $+2P\bar{\infty}$, etc. according to the length intercepted on the vertical axis.

Vertical prisms also consist of a set of four faces intersecting in parallel edges, which edge is in this case parallel to the vertical axis. The symbol ∞P is that of the unit vertical prism.

The *clino-pinacoid* consists of a pair of faces parallel to the plane of symmetry, and therefore parallel to the vertical axis and the clino-axis. Its symbol is $\infty P\dot{\infty}$.

The *ortho-pinacoid* also consists of a pair of parallel faces placed at the front and the back of the crystal, being parallel to the vertical axis and the ortho-axis. Its symbol is $\infty P\bar{\infty}$.

The basal pinacoid or *base* consists of a pair of faces parallel to the axes $\bar{b}$ and $\dot{a}$; the symbol is $0P$.

In this system it is clear that none of the simple forms described above can completely enclose space; all monoclinic crystals are therefore combinations of forms. Further, it is obvious that there is only one form, namely the clino-pinacoid, which is fixed in position for us, this being parallel to the plane of symmetry. The other faces will belong to one or other of the forms detailed above, according to our choice of the vertical axis and the clino-axis. For each mineral it is necessary therefore to make an arbitrary selection of these axes, and having made the selection to adhere to it for the same mineral.

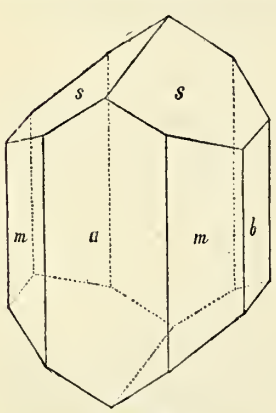

Fig. 82.
Monoclinic crystal (Augite).

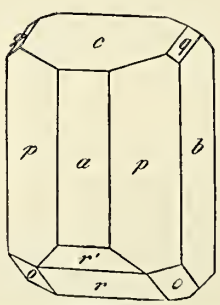

Fig. 83.
Monoclinic crystal (Felspar).

In the crystal of augite shown in fig. 82, the face marked b is one of the two parallel faces of the clino-pinacoid and is parallel to the plane of symmetry of the crystal. The ortho-axis will be perpendicular to this face; and for vertical axis we may select an axis parallel to the edge between the faces m and b (or a and m); and for

the clino-axis an axis parallel to the edge between s and s. The face a will then belong to the ortho-pinacoid; the four faces m will be the vertical prism; and the form s a clino-dome. It is more usual, however, to denote in augite the faces s as those of the primary pyramid $-P$, since on other crystals of this mineral other faces and edges are developed which give a more convenient set of axes.

Fig. 83 shows a monoclinic crystal of felspar (like that in plate 1, fig. 1, in which, however the faces a are absent). The face b is the clino-pinacoid parallel to the plane of symmetry; and we select the vertical axis parallel to the edge p/b, and the clino-axis parallel to the edge c/q. a is then the ortho-pinacoid, p the vertical prism, c the base, q a clino-dome, r and r' are positive ortho-domes, and o a positive hemi-pyramid. The Naumannian symbols of these forms are: —

$$b = \infty P \breve{\infty}, \quad a = \infty P \bar{\infty}, \quad p = \infty P, \quad c = 0P,$$
$$q = 2P \breve{\infty}, \quad r = P \bar{\infty}, \quad r' = 2P \bar{\infty}, \quad o = P.$$

Examples of monoclinic crystals are furnished by the minerals felspar (plate 60), augite (plate 65), hornblende (plate 66), and gypsum (plate 79).

Triclinic System.

On crystals of this system all the faces and all the edges intersect in oblique angles. The only element of symmetry present is the centre of symmetry; so that corresponding to each face there must be a parallel face on the opposite side of the crystal. It follows that the three crystallographic axes will be all dissimilar and of unequal lengths, and that they will be inclined to one another at oblique angles (α, β and γ). These axes are arbitrarily chosen parallel to any three edges (which are not parallel) of the crystal: it is usual to place one vertically and this is called the $\dot{c}$ or vertical axis; a second, placed from right to left is called the macro-axis $\bar{b}$; and the third, which is directed towards the observer, is called the brachy-axis $\breve{a}$.

Each form consists only of a pair of parallel faces, but from analogy with monoclinic and rhombic crystals we may conveniently refer to them as pyramids, prisms and so on, according to their positions with respect to the crystallographic axes.

Pyramids, then, are pairs of faces which intersect all three axes; and from their positions they may be distinguished by the Naumannian symbols P', $'P$, $P_{,}$, $_{,}P$, according to the octant in which they lie, that is right and above, left and above, right and below, and left and below, respectively.

Prisms are pairs of faces which are parallel to one of the axes: vertical prisms, $\infty P'$, $\infty' P$, parallel to the vertical axis; brachy-prisms or brachy-domes, $P \breve{\infty}$, parallel to the brachy-axis; and macro-prisms or macro-domes, $P \bar{\infty}$, parallel to the macro-axis.

Pinacoids are those pairs of faces which are parallel to two axes: the brachy-pinacoid parallel to $\breve{a}$ and $\dot{c}$; the macro-pinacoid parallel to $\bar{b}$ and $\dot{c}$; and the basal pinacoid or base parallel to $\breve{a}$ and $\bar{b}$. Their symbols are $\infty P \breve{\infty}$, $\infty P \bar{\infty}$ and $0P$ respectively, as in the monoclinic and rhombic systems.

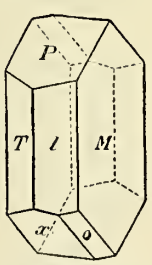

Fig. 84.
Triclinic crystal (Felspar).

These simple forms cannot exist alone, and all triclinic crystals must necessarily be combinations of forms. Fig. 84 represents a crystal of the variety of felspar known as albite. The $\breve{a}$ axis is taken parallel to the edge between the faces P/M, the $\bar{b}$ axis parallel to the edge between P and the larger face x at the back, and the vertical $\dot{c}$

axis parallel to the edge T/l. T will then be a left vertical prism $\infty' P$, l a right vertical prism $\infty P'$, M the brachy-pinacoid $\infty P \breve{\infty}$, P the base $0\,P$, x a macrodome $P \breve{\infty}$, and o a pyramid $P_{,}$.

Examples of minerals which crystallize in this system are albite (plate 61), axinite (plate 51), and copper-vitriol (plate 14).

Forms of Growth of Crystals.

In the foregoing sections we have given a brief account of the more important forms of crystals, but have considered them to be ideally developed with all the similar faces of the same size. This scarcely ever happens to be the case in nature, and we find considerable variations in the forms even on crystals of the same kind. It would, in fact, be scarcely possible to find two crystals of a mineral which are exactly alike: they all show greater or smaller differences, depending on the manner in which they have grown.

The regularity of the growth of crystals will be greater if the material for their growth is supplied to an equal extent on all sides, if the growth has taken place more slowly, and if there are no adverse conditions to hinder the growth. Under the most favourable conditions the crystal may perhaps assume an almost perfect form. But under less favourable conditions, when the material is supplied in unequal amounts on different sides, or when the growth has taken place rapidly, the crystals which result are distorted in form (compare p. 13). These distorted forms may have the appearance of unfinished crystals; or they may be delicate and branching, with a striking resemblance to the forms of plants, looking, indeed, so little like crystals that we are not disposed at first to recognize them as crystals. Such forms are familiar to all of us in the frost-flowers which grow on a window-pane in the winter, or the snow-flakes with their beautiful and extremely varied star-shaped forms. These forms are but the result of the rapid crystallization of water when lowered in temperature to the freezing point. Similar forms, due to peculiarities in the conditions of growth, are also frequently met with amongst minerals. Illustrations of irregularities in the forms of growth of minerals are given on plate 2, and examples may also be found on several other plates, more particularly those representing gold, silver and copper.

Figs. 1—4 (plate 2) show the common mineral iron-pyrites exhibiting different forms of growth, the first being an ideally developed octahedron. In fig. 2 we still see distinctly the octahedral form of the crystal at its summit, but round the sides the form is less regular and broken up with interspaces: in this instance the growth of the crystal has taken place mainly in the direction of the vertical axis, more material having been supplied to the top of the growing crystal than to its sides. This is still more emphasized in fig. 3, where material has been supplied only along the upper edges and not on the faces themselves, and the crystal has grown upwards like a column. In the extreme case, illustrated in fig. 4, the growth of the iron-pyrites has been confined between the layers of a slaty rock, and the result is the delicate branching forms like frost-flowers.

Branching forms of this kind are called dendritic forms, from the Greek, dendron, a tree. Another example of this form of growth is shown in fig. 5, representing the mineral wollastonite which has grown in a rock crevice.

The artificially prepared crystals of metallic bismuth shown in fig. 10, illustrate, as in the crystal of iron-pyrites, the growth of crystals along their edges, leaving vacant spaces or hopper-shaped depressions in place of the faces. That this is a result of a rapid and hurried crystallization we can only conjecture in the case of the natural crystals of iron-pyrites; but in the case of these artificial crystals we know that the material has crystallized rapidly from a molten condition. Similar hopper-shaped depressions are often shown on the faces of quartz crystals from Poretta near Bologna (fig. 8); but whether this also is a result of rapid growth it would be difficult to say. Sometimes it may happen that these cavities on the faces may become partly filled up by a later growth of material; and in this way we may explain the presence of cavities enclosing liquid in crystals, representing, in fact, some of the mother liquor in which the crystal has grown.

An incompletely finished crystal is shown in fig. 9, where we see a crystal of violet quartz (amethyst) partly surrounded by a later growth of colourless quartz (rock-crystal). This later growth has taken place mainly at the sides, but it will be seen that the amethyst has made an attempt to grow at its summit. Had the crystal remained in its home embedded in the rock and had the conditions necessary for its growth been uninterrupted, it would perhaps have continued to grow until the pyramid was completed.

Fig. 85.
Gypsum from Cornwall, with "pyramids of growth".

In the colourless shell of rock-crystal surrounding a nucleus of amethyst, we have an example of shelly growth. Still more pronounced cases of shelly growth are sometimes shown by common quartz, see for example, fig. 11, plate 52. Sometimes, when the shells are arranged closely together and are differently coloured, the banding of the crystal is especially conspicuous (fig. 4, plate 42; fig. 3, plate 47; fig. 6, plate 70; fig. 2, plate 76). In such cases it is obvious that the growth of the crystal has taken place by the addition of layers of material on its faces, and that at different stages of the growth there have been slightly different conditions and different colouring matters present. The successively larger layers piled on a face in this manner form together a pyramid, the base of which lies in the face of the crystal and the apex is at the centre of the crystal; these are known as "pyramids of growth". They are shown, for example in fig. 8 of plate 56, which represents a cross-section of a crystal of amethyst, with three colourless sectors alternating with three violet-coloured sectors. In the accompanying figure (fig. 85) of a gypsum crystal two "pyramids of growth" on opposite sides of the centre are transparent, while the two others are clouded by enclosed impurities.

Another form of growth is shown in fig. 7 of plate 2, representing reticulated galena from the St. Paul mine at Welkenraedt in Belgium. The thin rods or branches of galena interlace at angles of 90° in three directions parallel to the edges of the cube. The interspaces between this network are finely encrusted with yellow zinc-blende. A somewhat similar form of growth is often seen in magnetite (fig 1, plate 59), in which a number of minute octahedral crystals are arranged in rows parallel to the axes. In fig. 2 of the same plate are shown cauliflower-like growths of a mineral which is probably augite.

Several other forms of growth may be distinguished by names borrowed from objects whose shapes the forms assume. For instance, mossy, filiform or wiry, leafy, etc. Examples of these are often to be seen in the native metals gold, silver and copper. We shall see further on that in each of these forms of growth, and especially in the leafy forms, there is a regularity in the arrangement of the particles of which they are composed.

Quartz crystals showing various peculiarities of growth and distorted forms are represented on plate 2a. We have already seen from figs. 8 and 9, plate 1, that the typical form of a quartz crystal is that of a six-sided prism surmounted by a six-sided pyramid: we have further seen that the faces of the pyramid are of two kinds, and represent two rhombohedra in combination. All the crystals of quartz represented in plate 2a are set up in corresponding position to those in plate 1, the principal axis being vertical and a prism face to the front. Fig. 1 has already been referred to as an example of a distorted crystal (p. 14), being flattened in one direction owing to the large development of one pair of parallel prism faces. Fig. 2 shows a twisted crystal of quartz, like that of figs. 12*a* and *b*, plate 2; the latter is, however, placed with the principal axis horizontal. These have resulted by the growing together of several individual crystals not quite in parallel position, but each turned through a small angle with respect to the one next to it. The twisted crystal in fig. 3 does not show so distinctly this composite nature of smaller crystals, but it still shows the twisted form. The large triangular faces of the trapezohedron show that the crystal in fig. 2 is a left-handed crystal of quartz, and in fig. 3 a right-handed crystal: the twist of each crystal is also in the same direction, fig. 2 having a left-handed twist, and fig. 3 a right-handed twist.

The quartz crystal depicted in fig. 5 has a helical twist about its vertical or principal axis; those in fig. 2 and 3 are twisted about a horizontal axis. These crystals were attached to the rocky matrix at the ends of the axes about which they are twisted: in fig. 5 at the lower end of the vertical axis, and in fig. 2 and 3 at the right-hand and left-hand sides of the crystal respectively. The question may be asked, what is the cause of this twisting of the crystals? Since the crystals have grown freely in a cavity in the rock it is clearly not due to the influence of any external force, but must be due to a peculiarity of the growing material itself, whereby the small particles place themselves in positions not absolutely parallel to their neighbours. There is here a regularity of a certain kind in the growth, which we will consider further on when we come to consider twin intergrowths of crystals.

A remarkable instance of distortion is afforded by the bent crystal of quartz shown in fig. 4. Several suggestions may be made to account for this bending. Has the crystal, during its growth, reached an unyielding obstacle round which it has grown, as the root of a tree grows round a stone? Or has the crystal, during its growth, been subjected to a continued pressure from one side causing it to deviate from its proper direction, like the branches of a tree exposed to wind mainly from one quarter? Or again, has the crystal been bent by some pressure applied to it after the completion of its growth? This would be a difficult question to answer, but the explanation last suggested is perhaps the most plausible, and for the following reason. Consider a wax model of a quartz crystal with the prism faces marked with the horizontal striations. If we subject this to a pressure from one side it will be gradually bent; and the striations on the prism faces on the inner side of the bend will be pressed closer together, while those on the outer side will come to be wider apart: this is how the striations are actually arranged on the natural crystal.

The distortion shown by the crystal in fig. 7 is more readily explained. Here, clearly, the crystal has been actually broken by a sudden and violent movement of the rocks in which it was enclosed, possibly during an earthquake. Subsequent to the fracture, the growth of the crystal has continued, and the broken portions have been welded together by the accretion of new material. Broken crystals which have been healed in this way are by no means uncommon.

Instances proving a later period of growth in quartz crystals are shown in figs. 8 and 9 of plate 2a: in the former the growth has been continued in a small crystal attached to the side of the larger one. In fig. 9 the later growth has taken place at the apex of the crystal, and we have a columnar crystal surmounted by a shorter and thicker crystal: this is known as "sceptre-quartz". Fig. 9 of plate 2 also shows a later growth on quartz. And in fig. 6 of the same plate the dark violet rhombohedral crystal of calcite has continued its growth as colourless crystals of prismatic habit.

Intergrowths of Crystals of the same substance.

Crystals occur usually intergrown with others of the same kind, either as irregular groups or aggregrations of crystals (plate 79, fig. 5), or grouped in parallel position, or in twinned position.

In cases of *parallel growth* the similar faces and edges of the several crystals are parallel to one another, and it will readily be seen that the faces which are parallel reflect light simultaneously. A good example of parallel growth is shown in plate 2, fig. 6, in which the several prismatic crystals of calcite are not only parallel to one another, but are also in parallel position with respect to the central rhombohedron of calcite around which they have grown. Since there are no similar faces on the prismatic and rhombohedral crystals, their faces will, of course, not be parallel, but their axes are parallel and so are the cleavages of the calcite in the two portions. In the large specimen of barytes represented in plate 77 the crystals have grown in parallel position.

In many cases there may be attempts at parallel growth with a greater or less deviation from the true position. Successive particles may be inclined to one another at only a small angle from the true position of parallelism, but between the first and last there may be quite an appreciable deviation in position. In this way we may have considerable variation in the forms of aggregation of crystals. An example of this is shown in fig. 11 of plate 2, representing a specimen of haematite from St. Gotthard: here a number of small six-sided plates have grown together in nearly parallel position, but in such a manner that the composite crystal (which still shows the hexagonal outline) has a rosette-like form, and the specimen is called an "iron rose". Sheaf-shaped crystals of stilbite (plate 64, fig. 1) and the saddle-shaped crystals of dolomite (text-fig. 86) are also due to this sub-parallel aggregation of smaller crystals: so also are the twisted crystals of quartz already described.

Twinned crystals. — Some crystals may be seen to consist of two individual crystals of the same mineral grown together in a certain symmetrical manner, but not in parallel position. The two portions may interpenetrate, or one portion may have grown on the other.

In fig. 87 we have the interpenetration of two cubes, one of which is drawn in the normal position with four of its edges vertical. It will be noticed that at two

points the corners of the two cubes are coincident; and if we imagine the cube to be combined with the octahedron (as in fig. 25) the octahedral faces on these two corners will be common to the two crystals. If further, we imagine the crystal to be rotated about an axis perpendicular to these two octahedral faces, i. e. an axis joining the two coincident corners of both cubes, we can bring one cube into the position of the other by rotating it through 180°. Or again, we may imagine the compound crystal to be cut in two equal portions by a plane parallel to this octahedral face, and it will then be seen that the one half is the symmetrical repetition of the other half across this plane. The two cubes are therefore grown together in a perfectly definite and symmetrical manner.

In fig. 88 there are two octahedra (each apparently half of the whole form) grown together with an octahedral face on each in contact, and in such a manner that one portion may be brought into the position of the other by a rotation of 180° about an axis perpendicular to the face common to both. Further, the two portions are symmetrical with respect to this common plane, one portion being the mirror-reflection of the other across this plane.

Regular intergrowths of this kind of two crystals of the same mineral are known as twinned crystals or twins. The two individuals of the twin have one plane on each

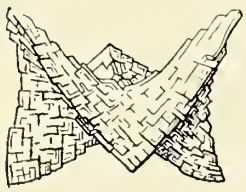

Fig. 86.
Saddle-shaped crystal of Dolomite
(After Tschermak).

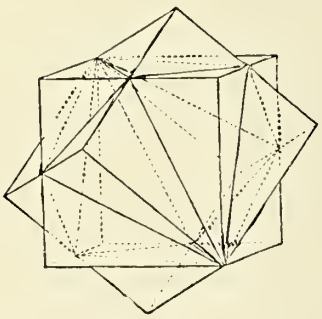

Fig. 87.
Interpenetration twin of two cubes
(Fluor-spar).

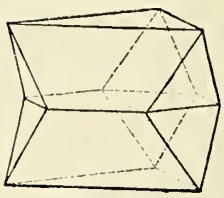

Fig. 88.
Contact twin of two octahedra
(Spinel).

in common, and across this plane one individual is the mirror-reflection of the other individual: this plane is called the twin-plane. When the two individuals interpenetrate one another, as in fig. 87, the intergrowth is called an interpenetration-twin; when they are in contact only, as in fig. 88, it is called a contact-twin.

A twinned crystal may be derived from two simple (i. e. untwinned) crystals by first placing them side by side in parallel position, and then turning one of them through 180° about an axis, called the twin-axis, which is perpendicular to the twin-plane. It may readily be seen that a plane of symmetry of a crystal cannot be a plane of twinning, since rotation about an axis perpendicular to such a plane would simply bring the crystal in a similar position again. Contact-twins are in many cases much flattened parallel to the plane of twinning, and the two portions look more like half crystals (fig. 88). The relations of twinned crystals may be very readily demonstrated by the aid of wooden models: the simple form is sawn through the middle and the two halves rotate one on the other about a peg, giving either the simple form or the twinned form according to their relative positions. Twinned crystals may usually be recognized by the re-entrant angles between their faces, as in all the figures here given of twins, but these are not invariably present. It should be remembered that an accidental and irregular intergrowth of two or more crystals will also show re-entrant

angles between the faces, but these will not be disposed in the same symmetrical manner as in twins.

In the *cubic* system the twin-plane is very often a face of the octahedron, as in the examples (figs. 87 and 88) already given. The twinned octahedron of fig. 88 is a common type, and, being especially well shown by the mineral spinel, it is called the spinel-twin. The same kind of twin is also often to be observed in the leafy forms of gold and silver, and will be described further on.

In the *tetragonal* system the twin-plane is most often a pyramid face, which is usually taken as a pyramid of the second order. The crystal of cassiterite (tin-stone) represented in fig. 89 is a combination of the primary pyramid $s = P$ and the vertical prism $m = \infty P$. The twin-plane is a face of the pyramid of the second order $P\infty$ which truncates the edge between two s faces at the top of the figure. Such twins are common in cassiterite (plate 38) and rutile (plate 39).

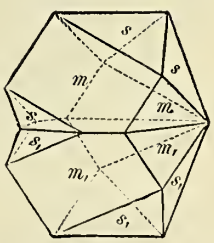

Fig. 89.
Tetragonal crystal twinned on a face of the pyramid of the second order (Cassiterite).

In *rhombohedral* crystals of the hexagonal system the basal plane or a rhombohedral face are common twin-planes. The scalenohedron (compare fig. 68) twinned on the basal plane gives the twin represented in fig. 90; in which the lower half has been turned through an angle of 180° about the principal, vertical axis. In the twinned scalenohedron similar edges, over which the angle is either obtuse or acute, come opposite above and below, and the edges at the middle of the crystal are horizontal. A twinned scalenohedron of calcite is represented in plate 73, fig. 6.

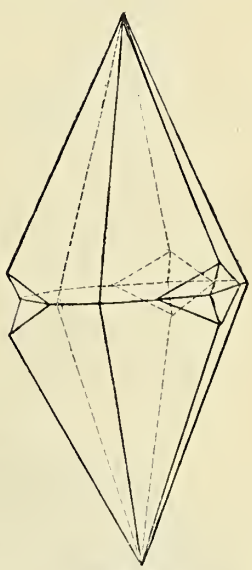

Fig. 90.
Scalenohedron of calcite twinned on the base.

In *rhombic* crystals the twin-plane is usually a prism face, less often a pyramid face. The crystal of aragonite in fig. 91 is bounded by the vertical prism $m = \infty P$, the brachy-pinacoid $b = \infty P\breve{\infty}$, and the brachy-dome $k = P\breve{\infty}$; and the second individual is so grown on the first that a face of the vertical prism is common to both, the two portions being symmetrical across this plane. A further description of these twins will be given under aragonite (plate 74) and cerussite (plate 17).

In *monoclinic* crystals the twin-plane is often the ortho-pinacoid, sometimes the base or a clino-dome. An augite crystal (fig. 82) when twinned on the ortho-pinacoid a gives the twin represented in fig. 92, where it is readily seen that the two portions are symmetrical about a plane parallel to a.

In *triclinic* crystals any face may be a twin-plane, but usually it is one of those chosen for a pinacoid.

Sometimes in the same crystal the twinning may be repeated several times on the same twin-plane: the first, third, fifth etc. portions will then be in parallel position with each other, and the second, fourth, sixth etc. will also be parallel, but adjacent portions will be in twinned position with respect to each other. Repeated twinning of this kind when the several portions are quite thin gives rise to a lamellar structure of the crystal; and in some instances the twinning is only rendered obvious by the striations produced by the lamellae on the faces. This is shown in the crystal of aragonite in fig. 93. The portion to the front is as in fig. 91. But the second

portion is quite thin; the twinning is repeated on the same prism face three more times, and the last (fifth) individual is parallel to the first. The crystal then looks like a simple crystal with fine striations on its faces (compare plate 74, fig. 3 and 4).

In other cases of repeated or multiple twinning the twinning may be repeated not on the same face but on other faces of the same form. For example, in the aragonite crystal in fig. 91, the twin-plane is the prism face *m* to the left, but the prism face *m* to the right is a similar face and may also be a plane of twinning. We may therefore have three aragonite crystals twinned together on both of the prism faces of one of them,

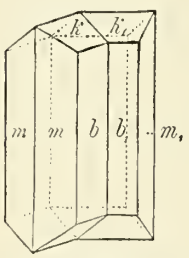

Fig. 91.
A rhombic crystal twinned on a prism face (Aragonite).

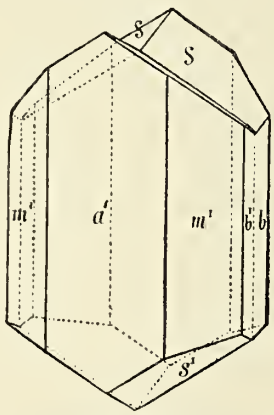

Fig. 92.
A monoclinic crystal twinned on the ortho-pinacoid. (Augite).

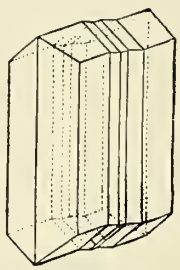

Fig. 93.
Repeated twinning in aragonite.

and since in aragonite the angle between the faces *m* and *m* is 116° the result will be a compound crystal resembling a hexagonal crystal in appearance (figs. 5—7, plate 74). In some other minerals with a prism angle still nearer to 120° this kind of twinning may produce forms which by the unaided eye cannot be distinguished from hexagonal crystals.

There are several instances of this kind among minerals in which twinning has the effect of increasing the apparent symmetry of a crystal: and such twins are called mimetic or pseudo-symmetric twins.

Regular intergrowths of crystals of different minerals: Enclosures in crystals.

Sometimes we meet with regular intergrowths between the crystals of two totally different minerals. An example of this is shown in fig. 9 of plate 28 and in text-fig. 94; on the basal plane of the large tabular crystal of haematite are laid a number of small prismatic crystals of reddish rutile, arranged in three directions at 60° to one another and parallel to the three horizontal crystallographic axes of the haematite. In fig. 95 a rhombic crystal of brown staurolite is grown in a definite position on a triclinic crystal of blue cyanite. Fig. 3, plate 67 shows under the microscope a regular growth of the two minerals augite and hornblende. The light coloured augite in the upper half of the figure has two sets of cleavages intersecting at an angle of 87°, and the darker hornblende (below) has also two sets of cleavages but at an angle of $124^1/_2{}^0$:

both minerals are monoclinic and they are so placed in relation to one another that their ortho-pinacoids and vertical axes are parallel.

In cases of regular intergrowth of this kind it is clear that one mineral must have exerted an influence over the other and constrained its particles as they crystallised to assume a definite orientation.

Enclosures of foreign material are very frequently present in crystals, and these will of course be more conspicuous and easily detected the larger the particles and the more transparent the crystal. The enclosed materials may consist of other minerals, of glassy matter, liquids, or gas. They may be distributed through the crystal without any regularity, or they may be arranged in bands or zones; or again, there may be a definite crystallographic orientation between the enclosing and enclosed minerals.

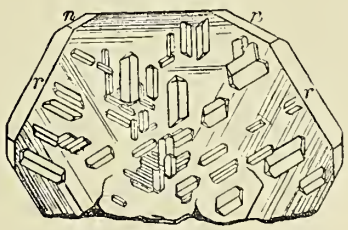

Fig. 94.
Regular growth of rutile on haematite. (After Tschermak).

Fig. 95.
Regular growth of staurolite on cyanite. (After Tschermak).

Enclosures of green actinolite in clear rock-crystal are shown in fig. 9, plate 54; of rutile needles in rock-crystal in fig. 4, plate 55; of glass in leucite in a microscope section of Vesuvian lava in text-fig. 96. Regularly arranged enclosures of glass and

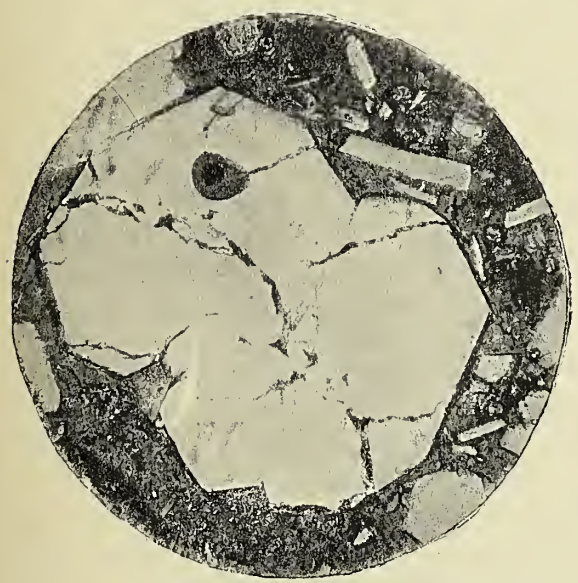

Fig. 96.
Glassy enclosures in leucite. Lava from Vesuvius.
Magnification 45.

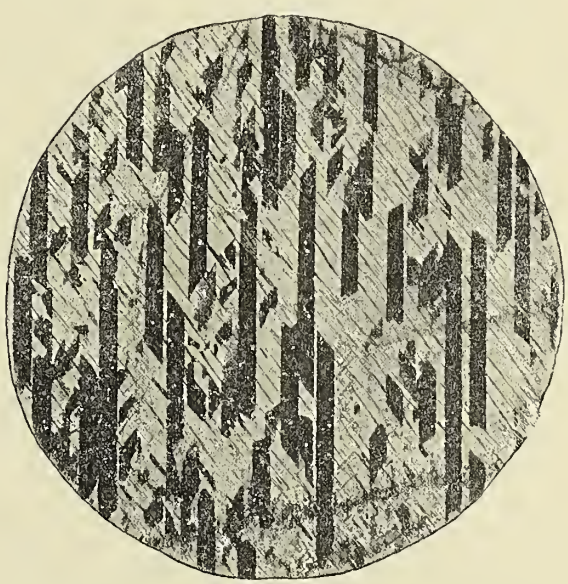

Fig. 97.
Dark mineral enclosures in (pale) hypersthene.
Magnification 45.

slag in a felspar crystal are shown in fig. 5, plate 59, and in leucite in fig. 4, plate 61a. Enclosures of liquid in a crystal may usually be recognized by the presence of a bubble of gas, which moves about as the crystal is moved. Cavities containing gases are usually only of microscopic size.

The presence of enclosures in crystals is of significance from several points of view. In some cases they give rise to peculiar colour phenomena which are not exhibited by minerals free from enclosures. The very thin brown plates, possibly of

ilmenite, often enclosed in hypersthene (fig. 97) are the cause of the coppery sheen so characteristic of this mineral (plate 65, fig. 2). The brilliant colours of labrador-felspar and the spangled reflections of sun-stone are also due to the presence of enclosed minerals.

The enclosure of glass and slag in a crystal proves conclusively that the crystal has crystallized from a molten mass; whilst the presence of liquid enclosures proves that the crystal has grown from a solution. Enclosures of liquid carbonic acid indicate that the crystal was formed under considerable pressure; and the presence of cavities containing petroleum in rock-salt (plate 70, fig. 6) points to the presence of petroleum during the period of crystallization of the rock-salt.

Grouping and aggregation of crystals.

In describing the forms of crystals we have assumed that the crystals have been completely bounded on all sides by faces. This will, of course, only be the case when the crystals have been freely suspended in the medium in which they grew, and material for their growth supplied on all sides. Crystals of this kind are called *embedded* crystals, since they have grown embedded in the matrix in which they are found (see, for example, plate 41, figs. 1—6; plate 47, fig. 13). More often crystals occur attached to the matrix, and they are then called *attached* crystals (plate 1, figs. 2, 5, 7). This must happen whenever the crystals have grown on the walls of rock crevices or cavities. At the point of attachment faces are, of course, not developed; but the freely developed faces of attached crystals are usually much brighter and sharper than are the faces of embedded crystals; and for this reason they are preferred by the mineralogist, since they give better measurements of the angles between the faces on the reflecting goniometer. Also, as a rule, attached crystals are richer in crystal-faces of different forms than are embedded crystals. When several embedded crystals have grown together they may be referred to as a cluster of crystals (plate 79, figs. 4 and 5); and when several attached crystals are grown together they form a group of crystals (plate 23, and frontispiece).

Rock-cavities completely lined with attached crystals are known as *geodes* or *druses* (plate 1, fig. 1). Sometimes these are so large that they are practically caves lined with crystals; as for example the large cavities containing rock-crystals and smoky-quartz in the Alps. Cavities lined with large crystals of gypsum or of calcite are also sometimes of considerable size.

When a number of crystals have grown so close together that they have interfered with each other's development, there may be no faces formed, and the whole mass consists of a compact aggregate of imperfectly formed crystals, which may be called a *crystalline aggregate*. Certain minerals have a strong tendency to grow in such crystalline aggregates, which may be of various kinds depending on the shapes of the constituent crystalline particles. For instance the structure of a crystalline aggregate may be platy (plate 41, fig. 8), fibrous (plate 41, fig. 9), columnar (plate 15, fig. 10), radiating (plate 22, fig. 5), shelly (plate 13, fig. 6). A granular structure may be coarse, or fine to compact, according to the size of the grains. Sometimes two forms of aggregation are present in the same specimen; for example, in malachite (plate 13, fig. 7), where alternate layers show a radially fibrous structure and a concentric shelly structure; and in kidney-iron-ore (plate 28, fig. 11) and limonite (plate 30, fig. 3).

Amorphous Substances.

Crystals, as we have seen, are bounded by plane faces and may be cleaved with greater readiness in certain directions than in others: their properties vary with the direction, and the ultimate particles of which they are built are disposed in regular order. Even when plane faces are absent, as in crystalline aggregates, the material possesses this regularity of internal structure. In contradistinction to this, there are a few minerals which possess no definite external form and no regularity in their internal structure: their particles are arranged according to no definite plan, and the properties of the mass are the same in every direction so that there is no particular direction in which the material may be more readily cleaved. Such substances are called amorphous. A good example is given by glass, and amongst minerals by opal. When an amorphous mineral exhibits an external form other than that of conchoidal fractured surfaces, this is rounded, being globular, botryoidal or reniform. This form has not been developed by the substance itself, as in crystals, but is the result of external influences, mainly of gravity, during the formation of the material.

Pseudomorphs.

Not infrequently we find minerals exhibiting a crystalline form which is characteristic not of that mineral but of some other mineral. The mineral which originally gave rise to the form has been destroyed and its place has been taken by some other mineral. This replacement of one mineral by another may be complete and the material of the crystal transformed throughout; or it may be only partial, the new mineral forming only the outer portion with the remains of the original mineral still forming the central portion of the crystal. Such altered crystals are called pseudomorphs. They have been formed when, in course of time, the conditions of environment have become different to those under which the crystal at first grew. The process of alteration is usually a purely chemical one, brought about by the aid of various solutions. Pseudomorphs are thus of particular interest and importance, for they tell us the chemical changes which minerals have undergone in the earth's crust. A few concrete examples will help to make the matter clearer.

The crystal represented in plate 3, fig. 3 has the form of the rhombic-dodecahedron, and its substance consists of the green mineral malachite. But malachite when it crystallizes freely takes the form of needle-shaped monoclinic prisms, and not cubic crystals as we have here. By examining and breaking open other crystals of the same kind we shall perhaps find some which consist on the outside only of green malachite and inside of a red transparent mineral. The crystal shown in fig. 2, which like the previous crystal is also from Chessy near Lyon in France, shows this clearly; the main part of this crystal consists of the red mineral, with the green malachite only in patches on the surface. In fig. 1 we have a crystal of the red mineral, cuprite, in its unaltered condition and exhibiting its own characteristic crystalline form. Cuprite is an oxide of copper, and when immersed in water containing carbonic acid it will slowly take up water, carbonic acid and oxygen, and be converted into malachite, a hydrated carbonate of copper. This alteration of cuprite to malachite has commenced in the crystal shown in fig. 2, and is completed in that of fig. 3. In the crystal shown in fig. 4 some of

the malachite appears to have been subsequently dissolved away, or perhaps the depressions on the octahedral faces were so in the original cuprite crystal (as in fig. 8, plate 2).

The example just described in detail may be briefly described as a pseudomorph of malachite after cuprite. Here the cuprite has been acted upon by a solution from which it could abstract carbonic acid, water and oxygen; but if the solution had been of another kind the result of the alteration would be quite different. If, for instance, the solution contains a substance having an affinity for oxygen, this element may be extracted from the cuprite and only the copper left. This has happened in the crystal represented in fig. 5, in which the exterior consists of native copper, though the interior still consists of cuprite, the alteration having been only partial. Here we have a pseudomorph of native copper after cuprite.

The crystals shown in figs. 7 and 8 of the same plate are regular cubes and their material consists of hydrated oxide of iron, a compound which never crystallizes in cubic forms. It will be noticed that the faces of these crystals are each striated parallel to only one of the cubic edges: and this feature we have already seen is especially characteristic of crystals of iron-pyrites (fig. 6), a mineral composed of iron and sulphur. That iron readily combines with oxygen and water with the formation of rust is a fact well known to everybody, and the same is also true in the case of the iron of iron-pyrites. When then, crystals of iron-pyrites are exposed to the action of underground waters containing oxygen their iron is converted into a hydrated oxide and their sulphur is removed in solution as free acid or as sulphates. If the alteration has been only superficial, the crystal when broken open will show an interior of still fresh iron-pyrites (fig. 9).

In the three examples of pseudomorphs so far given, the original substance of the crystal has undergone a chemical alteration of such a kind that the new material still contains one of the elements (copper or iron) that before were present: the other constituents have been exchanged. Pseudomorphs of this nature are called *alteration pseudomorphs.*

In other cases the new substance and the original substance of the pseudomorphous crystal have no constituent in common. Here the original substance has not been altered; it has been simply removed, and the space it occupied has been taken up by the new substance. A case of this kind is illustrated in figs. 10—12 of plate 3. The first figure represents fresh and unaltered crystals of calcite; in fig. 11 the calcite crystals are coated over with a deposit of red iron oxide; and in fig. 12 the calcite is entirely replaced by the iron oxide. The interaction of a solution containing iron on the calcium carbonate of the calcite produces a precipitation of iron oxide and a corresponding amount of calcium carbonate goes into solution. In the course of time the calcite will be in this way gradually removed and its place taken by the precipitated iron oxide. The interior of such pseudomorphs of red iron oxide (earthy haematite) after calcite are often, as in the specimen of fig. 12, filled with a deposit of massive quartz. That this iron was here deposited as oxide rather than as carbonate is readily explained by the readiness with which iron carbonate is oxidized. If, however, the solution had contained no oxygen available for oxidation then the new mineral might be deposited as a carbonate, providing, however, that this carbonate is more difficultly soluble than the calcium carbonate of the calcite. This is the case with dolomite and calamine, both of which minerals occur as pseudomorphs after calcite. Dolomite, which is a double carbonate of calcium and magnesium, often occurs only as a thin crust on calcite crystals, the interior of the crystal still consisting of calcite: but sometimes the

crystal may be entirely replaced by dolomite, or by calamine. Pseudomorphs of the kind described above (haematite after calcite), in which the whole of the original material is replaced, are called *replacement pseudomorphs.*

Less often do we find examples of pseudomorphs in which there has been no chemical change of the material, but only an alteration in the crystalline structure, and in the specific gravity and other physical characters. The crystal shown in fig. 13 of plate 19 has the form of a rhombic prism with pyramid, and is the form characteristic of the mineral brookite, which is a modification of titanium dioxide, TiO_2, possessing a specific gravity of about 4·0. The material of which this crystal now consists is likewise titanium dioxide; but it has a specific gravity of 4·2. Moreover its internal structure is not that of a single crystal, but we have an aggregate of numerous small prismatic crystals with no definite arrangement, which give a damask-like sheen to the surface of the crystal. These small needle-like crystals belong to the tetragonal system and have all the characters of the mineral rutile, which is another crystalline modification of titanium dioxide. Thus, without any alteration in chemical composition, the rhombic crystal of brookite has been transformed into a confused aggregate of tetragonal crystals of rutile. There has been a rearrangement of the minute particles of the substance, and the alteration may be said to be a molecular transformation. Changes of this kind can only take place with substances which occur in more than one crystalline modification, that is polymorphous substances; and their pseudomorphs are called *paramorphs.* The crystal described above is a paramorph of rutile after brookite. Other examples are given by the alteration of aragonite to calcite, both of which minerals consist of calcium carbonate (plate 74, fig. 9); and of tridymite to quartz. The crystal shown in fig. 14, plate 54, is a paramorph of quartz after tridymite; it has the form of tridymite, but the material of which it now consists is quartz; these two minerals are chemically identical, both consisting of silica (SiO_2), but different in their crystalline form and physical characters.

The Physical Characters of Minerals.

Of the physical characters of crystals those of hardness and cleavage first engage our attention.

By *hardness* is understood the resistance which a mineral offers to a point pressed against it: if the point be harder than the mineral, the mineral will be scratched. If we try the hardness of a number of minerals by pressing the point of a knife against them, we will find that some are readily scratched, others only with difficulty, whilst others will turn the point of the knife. We thus see that different minerals possess different degrees of hardness. For the convenience of being able to express in numbers the approximate degree of hardness of a mineral the following series of ten minerals, each one successively harder than the preceding, was selected by Professor F. Mohs to form a scale of hardness.

Mohs' Scale of Hardness.

1. Talc.
2. Gypsum.
3. Calcite.
4. Fluor-spar.
5. Apatite.
6. Felspar.
7. Quartz.
8. Topaz.
9. Corundum.
10. Diamond.

Talc, no. 1 on the scale, is the softest of minerals, and diamond, no. 10, is the hardest. Calcite, no. 3 on the scale, is harder than gypsum, no. 2, and a piece of gypsum is readily scratched by calcite. We have thus an easy means of determining the hardness of any mineral. For example, it will be found that rock-salt is capable of scratching gypsum, but that it can be scratched by calcite: rock-salt is therefore harder than gypsum, but less hard than calcite, and its degree of hardness is expressed as $2\frac{1}{2}$ on the scale. Again, garnet may be scratched by topaz, and it will itself scratch felspar; but it does not scratch quartz, nor does quartz scratch garnet. The hardness of garnet is therefore the same as that of quartz, and is expressed by 7.

Gypsum and other minerals with a hardness of less than 2 on the scale may be easily scratched with the finger-nail; and they are greasy to the touch (especially talc). Ordinary window-glass has about the same hardness as apatite, and it may be used as no. 5 of the scale. A good knife will scratch felspar with difficulty, but will not touch quartz.

The degree of hardness of a mineral differs on the faces of different crystal-forms, and in different directions on the same face. But usually these differences are so small that they can only be detected with the aid of specially constructed instruments. In a few instances, however, the difference is more pronounced, especially in certain minerals which possess a perfect cleavage. A cleavage face of calcite can be scratched by a crystal of calcite in the direction of the shorter diagonal of the rhomb-shaped face, but not in the direction of the longer diagonal.

In the scale of hardness given above, which is the one universally used by mineralogists, there are very wide differences in the actual degree of hardness between consecutive numbers. Taking the hardness of corundum as 1000, that of diamond = 140,000, topaz = 175, quartz = 120, felspar = 37, apatite $6\frac{1}{2}$, fluor-spar = 5, calcite = $4\frac{1}{2}$, gypsum = $1\frac{1}{4}$, and talc = $\frac{1}{33}$.

Cleavage. — Crystals of many minerals may be broken or split more readily in certain plane directions than in others. This important property of crystals is called cleavage. The direction of cleavage is always parallel to a possible face on the crystal, which is usually a prominently developed face of some simple form. Such a fractured surface is called the cleavage face, and a portion of a crystal entirely bounded by cleavage faces is called a cleavage form or cleavage fragment. The ease with which a crystal may be cleaved and the perfection of the resulting cleavage face vary widely in different minerals. In the same crystal there may be one or several directions of cleavage; if these are parallel to the faces of different forms, the character of the cleavages will be different; but if they are parallel to the several faces of the same form they will be similar in character. When a crystal possesses a cleavage parallel to one face of a simple form, it must also possess similar cleavages parallel to all the other faces of that form. Thus in fluor-spar, which readily cleaves parallel to the octahedron, there are four directions of perfect cleavage parallel to the four pairs of parallel octahedral faces (plate 1, fig. 6).

The best example of perfect cleavage is to be seen in mica, a mineral which cleaves in one direction parallel to the base. It can with ease be split into the thinnest of sheets, and these find an extensive application for the windows of stoves, for lamp chimneys, etc. Rock-salt has three directions of perfect cleavage parallel to the faces of the cube (fig. 3), and calcite also has three directions parallel to the faces of the primary rhombohedron (plate 73, fig. 8). When crystals of these minerals are broken, they almost invariably break along these directions. Zinc-blende has six directions of perfect

cleavage, parallel to the faces of the rhombic-dodecahedron (plate 20, fig. 9). Other minerals have less distinct cleavages; and in some, for example quartz, this property is almost or quite absent.

The presence or absence of cleavage can usually be made out from the inspection of the fractured surface of a crystal. Cleavage cracks may also be often seen inside a crystal, and on these coloured rings may frequently be observed.

The broken surfaces of minerals which do not possess any distinct cleavages are often quite characteristic in appearance. And according to the character of these surfaces, the *fracture* is distinguished as conchoidal, splintery, uneven, etc.

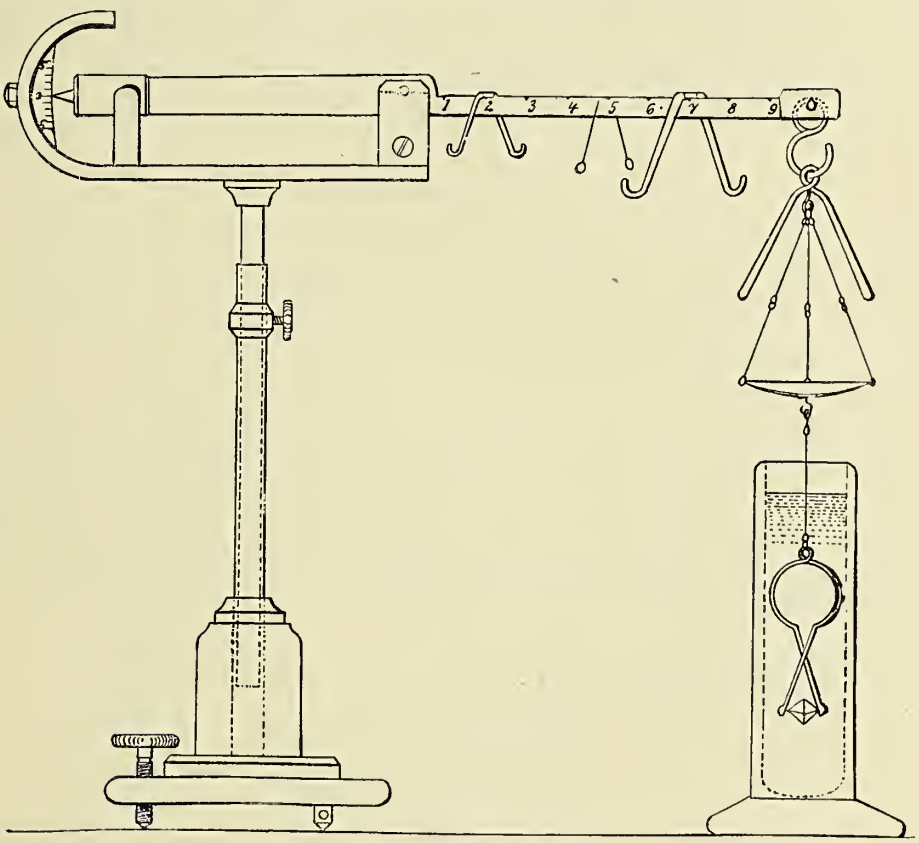

Fig. 98.
Westphal's balance for determining the specific gravity of small crystals.

Specific gravity. — The specific gravity of a body is a number which expresses how many times heavier that body is than an equal volume of water. When we know the weight and volume of any given body, we can calculate its specific gravity by dividing the weight of the body by the weight of an equal volume of water. The weight of the body is found by weighing, and its volume is determined by immersing it in water. The volume of the water displaced, which will be equal to the volume of the body, may be found by direct measurement. Usually, however, the volume is determined by weighing the body in water, when the difference between its weight in air and its weight in water will give the weight of the displaced water. These weighings may be conveniently made with a Westphal's balance (fig. 98), with which the specific gravity of specimens weighing from 0·2 to 2·0 grams may be determined. The instrument consists of a horizontal beam supported on knife edges. At the free end hangs a scale-pan, below which is a fine wire carrying a clip for holding the specimen.

The wire and clip are immersed in a vessel of water. The pointer on the left-hand end of the beam moves across the scale, and it is brought to the zero position by placing the weights or riders at suitable positions on the graduated beam.

When using the instrument, the clip must be first immersed in the water and the beam brought into the position of equilibrium with a rider, the position of which is noted. The mineral is then placed in the scale pan, and the rider or riders moved to the left until the beam is again in the position of equilibrium. The difference between the readings, given by the positions of the riders, is the weight of the mineral in air. The mineral must now be fixed in the clip and immersed in the water, care being taken that no fragments are broken off, and that no air bubbles are adhering. The riders must now be moved towards the right to restore equilibrium. The difference between the last two weighings will give the loss of weight of the mineral in water. This difference divided into the weight of the mineral will give the specific gravity of the mineral.

The series of operations will be perhaps clearer if we give a concrete example. The riders are of three sizes, the largest being the unit weight, and the others $\frac{1}{10}$ and $\frac{1}{100}$ of the unit. If they are hung on the hook at the end of the beam they have their full value, whilst if they are placed in the first notch on the beam they have only one-tenth of their full value. The positions of the four riders shown in the figure (fig. 98) indicate a weight of 1·725.

Supposing now, we wish to determine the specific gravity of a cut brown zircon such as that represented in plate 43, fig. 16, the clip is immersed in the vessel of water, and in order to bring the beam into equilibrium the reading of the weights is, let us say, 2·425. The stone is now placed on the scale pan, when the weights will be at, say, 1·614. Finally, the stone is fixed in the clip and immersed in water, and the weights re-adjusted to 1·786 to restore equilibrium. We then have: —

(1.) Tare without the stone	2·425
(2.) Tare with stone in scale-pan	1·614
Weight of stone	0·811
(3.) Tare with stone in water	1·786
Deduct the reading (2) . . .	1·614
Loss of weight in water . . .	0·172

$$\frac{\text{Weight of stone}}{\text{Loss of weight in water}} = \frac{0{\cdot}811}{0{\cdot}172} = 4{\cdot}71.$$

This result, 4·71, is the specific gravity of the specimen of zircon.

A very convenient and rapid method of determining the specific gravity of minerals, and especially of small fragments of them, is with the help of heavy liquids. The method depends on the fact that a body will float on a liquid which is heavier than the body, while if the liquid is lighter than the body, the latter will sink. If both the body and the liquid have exactly the same specific gravity, the body will remain suspended at any part of the liquid. It is therefore possible, when starting with a liquid heavier than the mineral to be tested, to so dilute the liquid and thus reduce its specific gravity, that the mineral will remain exactly suspended. If then we determine the specific gravity of the liquid, we know that of the mineral also. The specific gravity of the liquid may be determined by means of the Westphal's balance and a float in the liquid, or more conveniently, as mentioned below, with a set of indicators.

There are several heavy liquids which may be used for this purpose. The most convenient is methylene iodide, which at the ordinary temperature has a specific gravity of 3·33. This specific gravity may be successively reduced to rather less than 1 by adding increasing amounts of benzole. If a small fragment of a mineral or a faceted gem-stone be dropped into this liquid we shall know at once whether its specific gravity is greater or less than 3·33. If it sinks, the determination of its exact specific gravity cannot be made with the help of this liquid; all we know is that it must be greater than 3·33. If, on the other hand, it floats, the methylene iodide must be diluted with benzole, added drop by drop, until the stone remains suspended in the liquid, neither floating to the surface nor sinking to the bottom.

For purposes of distinguishing different minerals it is often not necessary to make an exact determination of the specific gravity, but only to find out whether a given specimen is lighter or heavier than, or has the same specific gravity as, a known mineral. For example, supposing we have two colourless faceted stones, one a topaz and the other quartz, and we wish to distinguish one from the other. Topaz has a specific gravity of 3·35, and quartz that of 2·65. If we drop the two stones into methylene iodide, the topaz will, of course, sink and the quartz will float. If now, the methylene iodide be diluted with benzole until the cut quartz just remains suspended, we shall find that a quartz crystal, which we know by its crystalline form, dropped into the liquid will also remain suspended. We thus see that the cut stone has exactly the same specific gravity as quartz, and for this reason it may be pronounced to be quartz.

Or again, supposing we wish to determine whether a small splinter of a mineral (which we know to be a carbonate from the fact that it effervesces in a drop of hydrochloric acid) is calcite (sp. gr. 2·72) or aragonite (sp. gr. 2·93). The mixture of methylene iodide and benzole is brought to a specific gravity of about 2·8, when the fragment, if aragonite, will sink, or, if calcite, will float. By placing in the liquid, together with the fragment to be determined, fragments which are known to be aragonite and calcite, the specific gravity of the fragment can be determined exactly.

This method, with the use of indicators, is indeed the most convenient. We may have a set of tubes containing methylene iodide and benzole in different proportions, and in each tube have recognizable fragments of one or more minerals to act as indicators, for example, gypsum (sp. gr. 2·32), quartz (2·65), calcite (2·72), tourmaline (3·02), apatite (3·20) etc.

Methylene iodide, though the most convenient liquid to use for the determination of the specific gravity of minerals, has one drawback, namely that of expense; but it need be used in only small quantities and without any waste if care be taken. A much cheaper liquid is bromoform, but, since this has a specific gravity of only 2·8 its application is much more limited.

The specific gravity of each kind of mineral (except in those cases where there is isomorphous mixing, as explained below) has always a fixed and definite value, which is characteristic for that mineral. It is necessary, however, that the determination should be made on material that is quite pure, with no signs of alteration nor with any foreign enclosures. For purposes of determination and for discriminating different minerals the specific gravity is a character of the greatest value.

Optical Characters.

The optical characters of crystals, or their action on light, are of the utmost importance to the mineralogist. But, since this is a somewhat technical branch of the subject, and the observations require the use of special instruments, we shall here only briefly mention the main points, reserving some others of interest till when we come to treat of the individual minerals. Those who wish to study the subject must refer to the textbooks on mineralogy, such as Professor H. A. Miers' "Mineralogy" (London, 1902) and Professor J. P. Iddings' "Rock Minerals" (New York, 1906).

Minerals possess different degrees of transparency and opacity; some are perfectly transparent, and others are perfectly opaque, and between these two extremes there is every grade of transition, even in one and the same kind of mineral.

Colour is also an important, though often variable, characteristic of minerals. In some minerals the colour is an essential character and peculiar to the kind of substance, but in many others it is non-essential and quite accidental. Examples of minerals which possess a colour peculiar to themselves are: the native metals (e. g., gold, copper), a few non-metallic elements (sulphur), minerals with a metallic lustre (iron-pyrites), and several other minerals which contain a metal (malachite). But in some of these cases it must be borne in mind that the colour may be hidden or obscured by a surface tarnish (for example, on native silver); it is therefore sometimes necessary to observe the colour on a freshly fractured surface of the mineral. Most other minerals, however, owe their colours to the presence of foreign colouring matter enclosed in them. This may be present as visible particles, for example, the small platy enclosures which give a brown colour to hypersthene (text-fig. 97, p. 47); but more often it is extremely finely divided, like the colouring matter in a solution. For this reason the colours exhibited by different specimens of one and the same kind of mineral may often be very varied. A good example of this is afforded by fluor-spar, which when quite pure and free from colouring matter is perfectly colourless and transparent; some of the colours actually exhibited by this mineral are represented on plate 71.

Usually the colour of a mineral is not the same when seen in fine powder as when seen in the mass. The colour of the powder of a mineral may be readily obtained by rubbing a piece of the mineral on a piece of unglazed porcelain. For this reason the colour of the powder is called the *streak* of a mineral, and this is often a character of importance. The streak of iron-pyrites is black, whilst the mineral in the mass has a brassy yellow colour. All minerals which contain foreign colouring matter give a white or grey streak; whilst those which have a colour peculiar to themselves give a coloured streak.

The *lustre* of minerals is another character depending on light. The different kinds of lustre of minerals are distinguished, by comparison with common objects, as metallic, vitreous (or glassy), pearly, silky, or greasy.

Refraction of light. — It is well known that when a stick is placed in a slanting position into water it appears to be bent. The reason for this is that the rays of light which are reflected by the stick alter their course on passing out of the water into the air: only those rays which are perpendicular to the surface of the water pass out without any deviation of their path. In the same way, light is bent or refracted whenever it passes from air into a denser medium: the ray of light is said to be bent towards the normal. If, in fig. 99, the line *G* represents the surface between a crystal and the air, then the line *LL* is the normal to this surface. A ray of light passing

from the air into the crystal takes the path shown by the broken line $S\ S$, which makes in the air an angle i with the normal, and in the crystal an angle r. The former angle i is called the angle of incidence, and the angle r is called the angle of refraction. Now, there is a fixed relation between these two angles, the ratio of the sines, $\frac{\sin i}{\sin r}$, being constant for the same kind of substance. This ratio can be expressed as a number, which is called the index of refraction or refractive index of the particular substance. When light passes from air into any crystal the value of the refractive index must be greater than unity (1), and it is always the same for crystals of the same mineral.

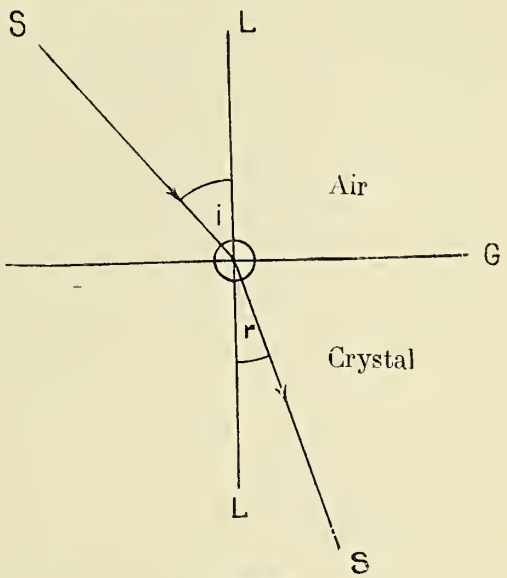

Fig. 99.
Refraction of light in passing from air into a crystal.

Another fact depending on the refraction of light, which is known to everyone, is that when ordinary day-light passes through a prism a coloured band or spectrum is formed. The explanation of this is that ordinary white light is composed of light of different colours, and that rays of differently coloured light are refracted to different amounts, red being refracted the least and blue the most. It is clear then, that the refractive index of a substance depends on the colour of the light, being less for red than for yellow, green and blue. The values of the refractive indices for light of different colours in some few minerals will be given further on. This breaking up of white light into its coloured constituents is known as *dispersion.* To the very high dispersive power of diamond are due the brilliant flashes of colour which are shown by the cut gem.

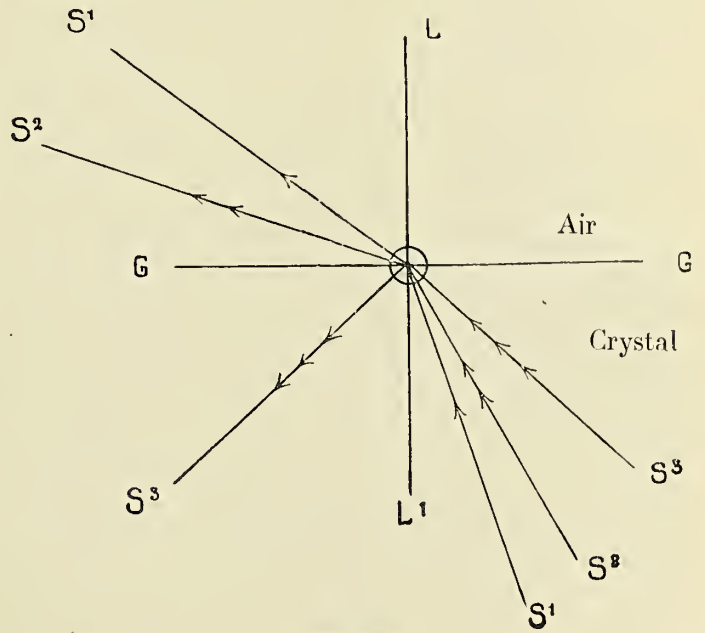

Fig. 100.
Refraction of light in passing from a crystal into air.
Total reflection in a crystal.

Rays of light in air falling onto the surface of a transparent crystal can in all cases enter the crystal. On the other hand, rays of light in a crystal are not always able to pass out of the crystal into air. When the ray does pass from the crystal into air it is bent away from the normal, as shown by the broken lines $S'\ S'$, $S^2\ S^2$ in fig. 100. A ray making a rather greater angle with the normal (but less than the angle made by S^3) will also be able to pass out, but it will glance along the surface in the

air. If the angle of incidence be increased slightly, to S^3, the ray will no longer be able to pass out of the crystal, but will be totally reflected at the surface G along the path S^3S^3 back into the crystal. This *total reflection* of light inside a crystal is an important character in minerals. As we shall see later, it plays an important part in the faceted gem-stones. The silvery reflections sometimes seen in quartz crystals are due to the total reflection of light from enclosed minerals, which, though they have a bright metallic appearance, usually consist only of chlorite.

Double Refraction. — When an object is viewed through a clear cleavage rhombohedron of calcite, such as a piece of "Iceland-spar", the object will appear double. The calcite has the peculiar property of breaking a ray of light which passes through it into two rays. This property of calcite is illustrated in plate 3a (the German word "Kalkspath" meaning calc-spar or calcite, and "Doppelbrechung" meaning double refraction). If the piece of calcite be laid over a dot on a sheet of paper and we look straight down through the calcite we shall see two images of the dot (for example, the dot at the end of the word "Kalkspath" in plate 3a). If now we turn the piece of calcite round, while it still rests on the paper, we shall see that one of the dots remains stationary, but that the other moves round in a circle about the first. We can therefore conclude that the ray of light corresponding to the stationary dot has not been bent or refracted, but that the ray corresponding to the moving dot has been refracted, although we are looking along the normal to the surface. The first is called the ordinary ray o, and the second the extraordinary ray e, since it does not obey the ordinary laws of refraction of light. If the rays were to pass out of the calcite obliquely the ordinary rays and the extraordinary rays would be differently refracted, and, corresponding to each of these, calcite possesses two indices of refraction, the ordinary and the extraordinary.

The double refraction of calcite from Iceland ("Iceland-spar") was described in detail by Erasmus Bartholinus in 1669; and as this mineral exhibits the phenomenon more strikingly than any other it is sometimes called doubly-refracting spar.

All minerals, except those which crystallize in the cubic system, are, however, doubly refracting; but most of them so feebly that their double refraction can only be detected with aid of a special instrument. Cubic crystals do not possess this property of splitting a ray of light into two, and, like glass and water and other uncrystallized substances, they are singly refracting. There are, however, in all doubly refracting crystals certain directions in which the refraction is single and not double. If, for instance, we cut from a calcite crystal a plate parallel to the base and look through it along the direction of the principal axis, only one image of a dot will be seen. Calcite is therefore singly refracting in the direction of the principal axis. Such a direction in a doubly refracting crystal is called an *optic axis.* Crystals of the tetragonal and hexagonal systems possess one optic axis, which coincides with the principal or vertical axis: such crystals are said to be *optically uniaxial.* We thus see that there is a close connection between the optical characters of a crystal and its crystalline form; those crystals with a single principal axis being optically uniaxial.

In crystals of the three other systems (rhombic, monoclinic and triclinic) there are two directions along which light is only singly refracted, and such crystals are consequently said to be *optically biaxial.* In the rhombic system the plane in which these two axes lie, or the optic axial plane, is parallel to one or other of the three planes of symmetry; in monoclinic crystals it is either parallel to or perpendicular to the single plane of symmetry; and in triclinic crystals there is no definite relation

between the position of the optic axial plane and the faces of the crystal. The discovery of these important relations between the optical properties of crystals and their external crystalline form is largely due to the patient labours of Sir David Brewster.

Recognition of Double Refraction.

The phenomenon of double refraction in crystals can be recognized by the unaided eye in but few minerals besides calcite, since in most cases the double refraction is only feeble, or the minerals are too cloudy. It can, however, be easily and readily recognized with the help of special instruments in which light is endowed with peculiar properties.

Fig. 101.
Nicol prism.

Light which has been reflected from a bright non-metallic surface, such as a sheet of glass blackened at the back, has no longer the same properties that it possessed before reflection, although to the unaided eye no difference can be detected. If the reflected light be allowed to fall on a second reflecting surface of the same kind, it will be found that in certain positions of the second surface the light will be again reflected, but that in other positions only a portion will be reflected. Light possessing this and other peculiar properties is said to be polarized: the vibrations in the ether here take place all in the same plane, whereas with ordinary light the vibrations take place in different planes.

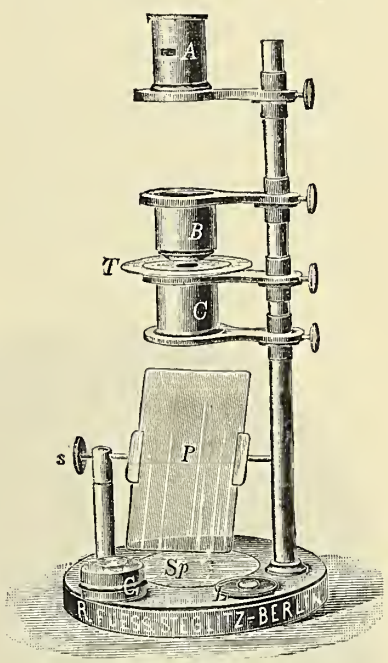

Fig. 102.
Polarizing apparatus or polariscope.

In a polarizing apparatus the reflecting mirror which gives rise to the polarization of the light is called the polarizer; and the second mirror is called the analyser. Usually, however, in place of a second mirror a more convenient and efficient form of analyser is used. This is a nicol prism (fig. 101); and in the better instruments a nicol prism is also used for the polarizer. A nicol prism is constructed from a long cleavage rhombohedron of calcite ("Iceland-spar") which is sawn diagonally into two pieces, and the two pieces cemented together again with Canada-balsam. A ray of light L entering the calcite will be split into two polarized rays e and o for which the indices of refraction are different; one of these rays (o) will be totally reflected at the surface of the Canada-balsam, whilst the other (e) passes through the prism along the path E. The light which passes through a nicol prism is therefore like that reflected from a non-metallic mirror, but here the light is completely polarized; *all* the vibrations take place in one plane, which is the plane parallel to the shorter diagonal of the nicol.

A simple form of polarizing apparatus or *polariscope* is shown in fig. 102. The light from a window is reflected by the mirror Sp onto the sheet of glass P which acts as the polarizer. This reflects polarized light vertically upwards through the instrument to the analyser, which consists of a nicol prism in the tube A. Between the polarizer P and the analyser A is a rotating table on which is carried the crystal under examination.

Use of the Polariscope.

This instrument requires a little adjustment before being used. After setting the instrument before a window, the analyser *A* should be removed and the light reflected by the mirrors upwards through the instrument. The analyser is now replaced, and as it is turned round in its collar it will be seen that the light is alternately cut out and allowed to pass through: the analyser has to be so placed that the light is cut out. The polarizer and analyser are then in crossed positions, that is their planes of vibration are at right angles. If now we place upon the table *T* a singly refracting cubic crystal, such as a cleavage fragment of rock-salt or one of the alum crystals which we have grown artificially (p. 9), we shall, on looking through the instrument, observe that the crystal still remains dark and has no effect on the polarized light. If, however, we place on the table a doubly refracting crystal or a fragment of one, such as a cleavage flake of mica or of gypsum, we shall see that the crystal not only causes light to pass through the instrument but that, as a rule, it appears brilliantly coloured. The colour actually seen will depend on the strength of the double refraction of the crystal, and also on the thickness of the crystal. With flakes of gypsum of varying thickness a range of vivid polarization colours may be obtained. The polariscope thus gives us an easy and ready means of recognizing the presence of double refraction in a crystal, or of distinguishing a singly refracting mineral from one that is doubly refracting.

If now we slowly rotate the table of the polariscope on which the flake of gypsum is placed, we shall see that the light gradually becomes fainter, until finally it is completely cut out and the gypsum will appear dark like the piece of rock-salt. On turning the table a little farther the light will gradually re-appear; and during a complete revolution of 360°, the light will be in this way cut out four times and re-appear four times.

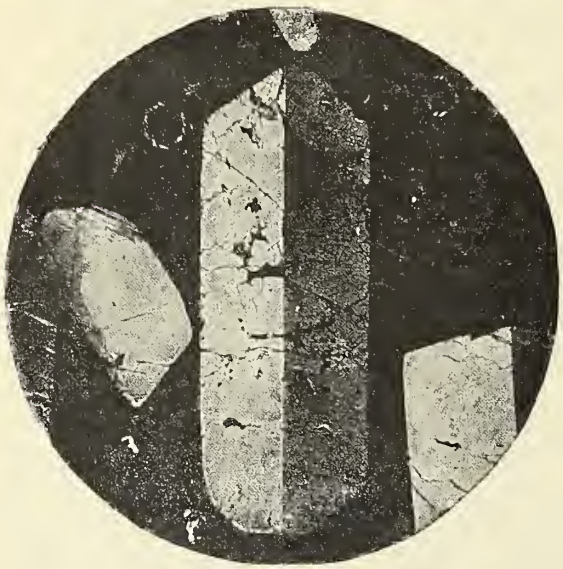

Fig. 103.
Twinned crystal of augite in polarized light. Kaiserstuhl, Baden. Magnification 20 diameters.

Where the doubly refracting crystal under observation consists of a single individual it will be equally illuminated in all portions, but if the crystal be a twin, the two individuals will be differently illuminated, one portion being dark while the other is light, and vice versa (fig. 103). This gives us an easy means of recognizing twinned crystals, especially when we are examining the crystals in a thin section of a rock. The repeated twinning of a cleavage flake of labradorite felspar as seen in polarized light is represented in fig. 1 of plate 61a. The bands are alternately light and dark; and as the flake is turned round on the table of the polariscope the light bands become dark and the dark bands become light. A similar, but finer, laminated structure due to twinning is shown in figs. 2 and 3 of the same plate. In cases of this kind the twinning would never be recognized by the naked eye, and it only becomes obvious when thin sections of the mineral are examined in polarized light.

If we examine in the polariscope a cube of sodium chlorate (which may be obtained by crystallizing the salt from an aqueous solution) or a slice of a quartz crystal cut perpendicular to the edges of the prism, we shall see that they allow light to pass through and that they appear coloured; and furthermore, as the crystal is turned round with the table the light is not cut out, as was the case with the doubly refracting crystals above considered. If now we rotate the analyser it will be seen that the crystal changes in colour; and if we use red light (by placing a sheet of red glass before the eye) we shall see that the light fades or becomes brighter, and that at a certain position of the analyser it is cut out altogether. Crystals which behave in this peculiar manner are rather exceptional and are said to be *circularly polarizing*: they have the property of rotating the plane of polarization of plane polarized light. The right-handed and left-handed characters shown by different crystals of quartz (p. 36) may be distinguished by their circular polarization. If we take two plates of quartz of equal thickness, one cut from a right-handed crystal (fig. 76) and the other from a left-handed crystal (fig. 75) we shall find that in the polariscope they will both give the same colours, but that the order in which these colours (red, yellow, green, blue) appear depends on whether the analyser is rotated to the right or to the left.

When a doubly refracting crystal is turned round in the polariscope into the position of darkness, it is said to be in the position of extinction, the light being then extinguished. The principal directions of vibration for light in the crystal are then parallel to the vibration directions of the polarizer and analyser. The latter are fixed directions in the instrument, and are usually marked by cross-wires in the eye-piece. If, when the crystal is in the position of extinction, these directions coincide with some prominent edge on the crystal, for example the prism edges of a quartz crystal, then the extinction is said to be straight, and the crystal is said to give *straight extinction*. If, on the other hand, these directions do not coincide with an edge of the crystal, the extinction is said to be oblique. This distinction between straight and *oblique extinction* is of importance, since it is of great assistance in determining the symmetry of crystals. On all faces of a crystal perpendicular to which there is a plane of symmetry the extinction will be straight.

In tetragonal and hexagonal crystals the principal axis is, as already pointed out, a direction in which the refraction is single and not double. If, therefore, we cut from one of these crystals (except quartz, which is circularly polarizing) a plate parallel to the base, that is perpendicular to the principal axis, and examine it in the polariscope, we shall find that it behaves exactly like a cubic crystal. This will, however, only be true when the light travels parallel to the axis of the crystal. In the polariscope as so far described we have considered all the rays of light to be parallel to the axis of the instrument, and thus our examinations have been made in *parallel polarized light*.

The polariscope can also be arranged so that the rays of light passing through the crystal are not parallel but convergent. And when crystals are examined in *convergent polarized light* they present phenomena of quite a different kind. For this purpose two systems of converging lenses are placed in the holders B and C (fig. 102) above and below the table T carrying the crystal. When an optically uniaxial crystal, cut as a plate perpendicular to the optic axis, is observed in the polariscope in convergent light we see what is called an *interference figure*. With white light (i. e. ordinary daylight) this consists of a set of concentric circular coloured rings intersected by a black cross. If light of one colour be employed, for instance that given by the sodium flame, the rings will be alternately light and dark (plate 4, fig. 1). No change takes place in this interference figure when the crystal is rotated with the table of the polariscope.

Such an interference figure is typical of tetragonal and hexagonal crystals. The number and sharpness of the rings will depend on the strength of the double refraction and on the thickness of the plate.

A section cut from a quartz crystal, although also uniaxial, shows a slight difference in the interference figure (plate 4, fig. 2). Here the coloured rings are circular and concentric as before, but the black cross extends only towards the centre as far as the innermost ring. This difference is characteristic of circularly polarizing crystals.

A plate cut in a certain definite direction from an optically biaxial crystal (belonging to the rhombic, monoclinic or triclinic systems) shows in convergent polarized light the kind of interference figure represented in plate 4, figs. 3 and 4. As the crystal plate is turned with the table of the instrument the figure alternately changes in form from one of these shapes to the other. In the normal position of the plate, when the vibration directions in the crystal coincide with those of the polarizer and analyser the figure is as in fig. 3, with a narrower arm and a broader arm intersecting the two systems of rings. When the crystal is turned through an angle of 45° into the diagonal position the black cross breaks up into the two branches of a hyperbola (fig. 4). Interference figures of this kind are shown by cleavage flakes of muscovite mica.

It is thus possible from an examination in convergent polarized light to distinguish in a uniaxial crystal whether it is circularly polarizing, but it is not possible to distinguish a tetragonal crystal from a hexagonal. By noting the distribution of colours in a biaxial interference figure it is possible to distinguish between rhombic, monoclinic and triclinic crystals, but it would be out of place in this book to enter into this interesting branch of crystal optics.

Dichroism. — Some doubly refracting crystals which are transparent and coloured show different colours when viewed through in different directions. This phenomenon is called pleochroism or dichroism. Some minerals show this very strikingly even to the unaided eye, especially so with the mineral cordierite, which for this reason is also known as dichroite. Usually, however, the presence of dichroism can only be detected with a special instrument, called a dichroscope. This consists essentially of a cleavage rhombohedron *p* of Iceland-spar with the ends squared off. At one end *T* of the tube carrying the calcite is a small square aperture (shown in the end view of the instrument), and at the other end is a lens *L*. Rays of light admitted into the instrument through the square aperture are split up by the calcite into two rays, and on looking through the lens a double image of the aperture is seen. If now a dichroic crystal be placed in front of the aperture the two images will be differently coloured. A yellowish green crystal of aquamarine (plate 44, fig. 12) placed with one of its prism faces against the aperture will give a pair of images which are coloured yellowish-green and sky-blue these colours corresponding to the ordinary ray and to the extraordinary ray respectively. If an optically uniaxial crystal be placed with its basal plane against the aperture of the dichroscope the two images will be coloured alike. It is therefore necessary when examining a crystal for dichroism to turn it about in front of the aperture of the dichroscope: in certain positions the two images will be coloured alike, while in certain

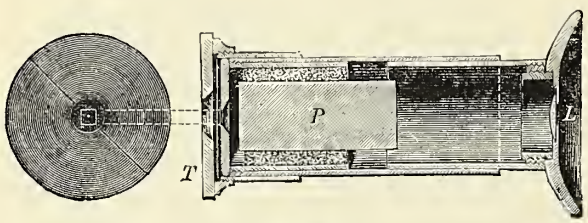

Fig. 104.
Dichroscope.

other positions of the crystal they will show a maximum difference in colour. The dichroscope is especially useful for the examination of faceted gem-stones.

Some other physical properties which are especially characteristic of certain minerals will be considered when we come to a detailed description of those minerals: for instance the magnetism of magnetite, and the pyro-electricity of tourmaline.

The Chemical Characters of Minerals.

The Constituents of Minerals.

The substance of minerals consists of chemical elements, which may be present either singly or two or more combined together to form a chemical compound. Minerals consisting of a single chemical element represent a native condition of these elements, for example, native gold, native silver, native sulphur, etc. The composition of a mineral is determined by the ordinary methods of chemical analysis: the methods of qualitative analysis being employed to determine what chemical elements are present, and the methods of quantitative analysis to determine their relative amounts.

Many of the common minerals may be recognized by the help of their external characters alone, such as hardness, colour, lustre, streak, cleavage and crystalline form. But it is often necessary also to perform some chemical tests, if only by way of confirmation. A few simple tests which are useful in this direction will be briefly mentioned, but for fuller details the reader must be referred to the text-books on analytical chemistry: a particularly useful book is G. J. Brush and S. L. Penfield's "Determinative Mineralogy."

We may test whether the mineral is soluble in water or in acids. If it dissolves in acid with the liberation of carbon dioxide, we know that it is a carbonate. By heating in a flame the fusibility may be determined. Or if a fragment of the mineral be heated in a glass bulb-tube we may find that it gives off water or a solid sublimate, or that it changes in colour. Many other simple tests may be made with the blowpipe, by means of which a small, oxidizing or reducing flame may be directed against a fragment of the mineral placed on charcoal: the mineral may thereby be fused or volatilized and we may obtain fumes with a characteristic odour, or there may be a coloured sublimate formed on the charcoal. Minerals containing a heavy metal when mixed in a powdered form with sodium carbonate and heated on charcoal before the blowpipe will in many cases yield globules or spangles of the metals which they contain. If the mineral contains sulphur in combination with the metal, this will combine with the sodium of the sodium carbonate and on placing the fused mass on a silver coin and adding water a black stain will be formed on the coin: this is a very simple and reliable test for determining the presence of sulphur in a mineral. Many metallic compounds when fused in a borax bead on a loop of platinum wire give a characteristic colour to the bead. Other substances impart a characteristic colour to the non-luminous flame of the Bunsen burner or of a spirit lamp: several minerals will give this coloration if a fragment be moistened with hydrochloric acid and held in the flame on a platinum wire. It is unnecessary in this place to enter into further detail of this kind: but certain tests which may be applied for the recognition of particular minerals will be mentioned under the minerals themselves.

Chemical formulae. — When the composition of a mineral has been completely determined by quantitative analysis, it is convenient to be able to express this composition

simply and shortly by means of a formula. The results of a quantitative analysis are expressed in percentages of the weights of each constituent: and from these figures the formula can be calculated. The formula states what elements are present, and how many atoms of each go to form the chemical molecule. Each element is represented by a symbol, which is the first or first two letters of the common or the Latin name of the element: thus N stands for nitrogen and Na for sodium (natrium). The smallest particle, or atom, of each element which is capable of entering into chemical combination possesses a definite weight which is characteristic of that element. The absolute weights of the atoms are of course unknown, but we can express their relative weights. The following is a list of the more important elements, with their symbols and atomic weights, that of hydrogen being taken as unity.

	Symbol	Atomic weight		Symbol	Atomic weight
Aluminium	Al	26·9	Molybdenum	Mo	95·3
Antimony	Sb	119·3	Nickel	Ni	58·3
Argon	A	39·6	Niobium	Nb	93·3
Arsenic	As	74·4	Nitrogen	N	13·93
Barium	Ba	136·4	Osmium	Os	189·6
Beryllium	Be	9·03	Oxygen	O	15·88
Bismuth	Bi	206·9	Palladium	Pd	105·7
Boron	B	10·9	Phosphorus	P	30·77
Bromine	Br	79·36	Platinum	Pt	193·3
Cadmium	Cd	111·6	Potassium	K	38·86
Caesium	Cs	131·9	Radium	Rd	223·3
Calcium	Ca	39·8	Rhodium	Rh	102·2
Carbon	C	11·91	Rubidium	R	84·8
Cerium	Ce	139·2	Ruthenium	Ru	100·9
Chlorine	Cl	35·18	Samarium	Sm	148·9
Chromium	Cr	51·7	Selenium	Se	78·6
Cobalt	Co	58·56	Silicon	Si	28·2
Copper	Cu	63·1	Silver	Ag	107·12
Fluorine	F	18·9	Sodium	Na	22·88
Gallium	Ga	69·5	Strontium	Sr	86·94
Germanium	Ge	71·9	Sulphur	S	31·83
Gold	Au	195·7	Tantalum	Ta	181·6
Helium	He	4	Tellurium	Te	126·6
Hydrogen	H	1·000	Thallium	Tl	202·6
Indium	In	113·1	Thorium	Th	230·8
Iodine	I	125·90	Tin	Sn	118·1
Iridium	Ir	191·5	Titanium	Ti	47·7
Iron	Fe	55·5	Tungsten	W	182·6
Lanthanum	La	137·9	Uranium	U	236·7
Lead	Pb	205·35	Vanadium	V	50·8
Lithium	Li	6·98	Ytterbium	Yb	171·7
Magnesium	Mg	24·18	Yttrium	Yt	88·3
Manganese	Mn	54·6	Zinc	Zn	64·9
Mercury	Hg	198·5	Zirconium	Zr	89·9

The formula of the mineral rock-salt, which consists of the chemical compound sodium chloride, may be expressed as NaCl, indicating that each molecule of this substance consists of one atom of sodium and one atom of chlorine in chemical combination; or in other words rock-salt consists of 22·88 parts by weight of sodium and 35·18 parts by weight of chlorine. In the same way the formula of iron-pyrites may be written FeS_2, that is one atom of iron combined with two of sulphur: the mineral therefore consists of 55·5 parts by weight of iron and 63·66 of sulphur.

In order to calculate the formula of a mineral we must therefore first know the amounts by weight of each element present, these amounts are usually expressed as percentages of the weight of the whole substance. Thus 100 grams of perfectly pure iron-pyrites will on analysis be found to contain 46·58 grams of iron and 53·42 grams of sulphur. By dividing these numbers by the atomic weights of the respective elements, we obtain the atomic ratios, that is the ratio of the number of atoms present of each element in the compound. Thus for iron-pyrites $\frac{46{\cdot}58}{55{\cdot}5} = 0{\cdot}84$, and $\frac{53{\cdot}42}{31{\cdot}83} = 1{\cdot}68$. Now the values 0·84 and 1·68 are in the ratio of 1 to 2, so that the molecule of iron-pyrites consists of one atom of iron in combination with two atoms of sulphur, as expressed shortly by the formula FeS_2.

Dimorphism and Isomorphism.

Dimorphism. — Sometimes we find one and the same chemical element or compound in crystals exhibiting different forms and with different physical properties. The chemical composition of the material is the same, but its crystallographic and physical characters differ. Thus, calcium carbonate is most frequently found as crystals belonging to the rhombohedral division of the hexagonal system, but it also occurs as rhombic crystals. These, then, are two distinct minerals, which are known as calcite (plates 72 and 73) and aragonite (plate 74) respectively. Calcite cleaves with ease in three directions parallel to the faces of a rhombohedron, it is optically uniaxial (plate 4, fig. 1), and has a specific gravity of 2·72. Aragonite, on the other hand, has no distinct cleavage, it is optically biaxial (plate 4, figs. 3 and 4), and its specific gravity is 2·93. These two minerals thus differ widely in character although they are identical in their percentage chemical composition, and they are therefore said to be dimorphous. Another good example of dimorphism is afforded by the element carbon, which occurs in nature as two crystallized minerals, diamond and graphite (plate 41). Here there is a very striking and marked difference in the appearance and physical characters of two minerals which are chemically identical. Diamond crystallizes in the cubic system, is transparent and heavy, and is the hardest of minerals; while graphite crystallizes in the hexagonal system, is opaque and less heavy, and is one of the softest of minerals. Cases are also known in which the same chemical substance crystallizes in three distinct forms: such substances are said to be trimorphous or polymorphous. A good example of this is given by the minerals rutile, anatase and brookite, all of which consist of titanium dioxide.

Isomorphism. — Many instances are known of minerals which are analogous in chemical composition and which at the same time exhibit similarity in crystalline form. Such minerals are said to be isomorphous. For example, the two minerals magnesite ($MgCO_3$) and chalybite ($FeCO_3$) are chemically analogous and both crystallize in

rhombohedra with nearly the same angles between the faces. Furthermore, they possess the peculiarity, which is a characteristic of isomorphous substances in general, that the substance of one may be replaced in the same crystal by an equivalent amount of the substance of the other: the same crystal may contain both magnesium carbonate and iron carbonate and still exhibit the characteristic rhombohedral form of magnesite or chalybite. Such intimate isomorphous mixing of two substances to form one and the same crystal is of extremely frequent occurrence amongst minerals. Less frequently are the two substances each collected in bands or zones in the same crystal, as would result if first one substance crystallized, and then a layer of the other substance was deposited on the crystal. Such zoned crystals of two substances may, however, be readily grown artificially: an octahedron of colourless potash alum if placed in a solution of chromium alum will continue its growth as a violet coloured octahedron.

When two or more minerals are isomorphous with one another they may be included in the same isomorphous group. If the substances are also dimorphous, there will be two parallel isomorphous series, thus giving an isodimorphous group. An example of this is seen in the calcite and the aragonite groups of carbonates.

Origin of Minerals.

We are apt to look upon minerals as permanent and unalterable; but, like animals and plants, they have a period of birth and growth, and later they may be altered and decomposed, their material giving rise to a new generation of other minerals. Minerals are formed in many different ways, and it is only rarely that we are able to trace out completely their mode of formation. Some have crystallized out from a molten rock mass, others have been deposited by vapours, but the majority have grown from aqueous solutions. The molten rock poured out as lava streams from volcanoes gives rise on its consolidation to minerals of various kinds, such as felspar, leucite, olivine, augite, magnetite, and others. The vapours and gases emitted by a volcano deposit solid materials near the crater of the volcano; for example, sulphur, rock-salt, haematite, etc. The water which is abundant everywhere on the surface and in the crust of the earth is capable of dissolving solid materials and depositing them again in other forms. From the largest of all solutions, the sea, immense deposits of rock-salt with associated beds of abraum-salts, gypsum and anhydrite have been formed. In the earth's crust water circulates in the cracks and crevices of the rocks, and in some cases is heavily charged with mineral matter, as is shown, for instance, by the springs of mineral water of various qualities. The mineral matter held in solution by these underground waters may under suitable conditions be deposited as crystallized minerals. For instance, on the evaporation of the water, gypsum crystals may be deposited in cavities. Or again, if two solutions containing different materials become mixed new compounds may be formed, and if these are only slightly soluble in water they will be deposited. The insoluble barytes ($BaSO_4$) may be deposited when, in a rock crevice, a water containing in solution a small amount of barium carbonate or barium chloride meets another solution containing calcium sulphate: by the interaction of the materials in the two solutions barium sulphate is formed, and being insoluble in water it is deposited on the walls of the crevice.

Weathering. — Water which falls as rain on the earth's surface takes into solution from the air and from the surface soil small amounts of oxygen, carbon dioxide and other

substances: and the water so charged will, on sinking into the rocks of the earth's crust, be able to react on various minerals. Pure water has very little action on most minerals, but when gases are present in solution most minerals, even the most resistant, will be slowly decomposed and dissolved. Crystals will commence to lose their brilliancy and lustre, becoming dull and rough on their surface: and finally they may be completely dissolved and carried away in solution; or certain constituents only may be dissolved and removed, leaving others in a powdery form. In weathering processes of this kind, it is only exceptionally that the form of the original mineral is retained, as in the pseudomorphs described above (p. 49). The water which has been the cause of this weathering and decomposition of the minerals has thereby gained mineral matter in solution, from which under other conditions new minerals may be deposited, and these in their turn will be subjected to weathering processes.

There are thus going on in the earth's crust slow but continual processes resulting in the formation and destruction of minerals. These changes in the inorganic world are in a way analogous to those in the organic world, but they are much slower. Further, they are essential to the existence of the organic world, for it is by the weathering of minerals that inorganic salts pass into solution and are then capable of being taken up by plants. Were it not for the weathering of minerals there would be no possibility of organic life, and the material of the earth's crust would belong solely to the mineral kingdom.

Special part.

The Ores and their Associates.

By the miner the term *ore* is applied to any mineral or mixture of minerals which can be profitably worked for the metal it contains. Mineralogists, however, would restrict the word to those minerals having a metallic appearance and containing a heavy metal. Quartz containing one ounce of gold to the ton is considered by the miner to be a rich gold ore; but as the gold is not visible to the unaided eye, the material looks exactly like ordinary massive quartz. On the other hand, the beautifully developed octahedral crystals of magnetite (plate 29 a) such as are found by mineral collectors in the Binnenthal in Switzerland, would be called an ore by the mineralogist, but not by the miner, since at this locality the mineral occurs too sparingly to be profitably worked for iron. When, howewer, magnetite occurs in large masses it is an important ore of iron.

For the miner to become thoroughly acquainted with the minerals present in his ore he must, like the mineralogist, study the minerals themselves, He would, for instance, be able to learn very little about the characters of native gold from an examination of a gold-quartz containing only one ounce of gold to the ton. In our description of the minerals which are of importance as ores we shall therefore select the most characteristic specimens, and draw attention to their prominent features, mentioning also their modes of occurrence and where they are found. In addition to details of importance to the miner, points of mineralogical and of general interest will be mentioned.

By the decomposition of metallic minerals in nature's laboratory various new minerals have been formed; these are often brightly coloured, and consist of the metal in combination with various mineral acids, such as carbonic or sulphuric acid. These secondary minerals occur in association with the metallic minerals from which they have been derived, and they may be considered as belonging to the same group or family. Some of them are included under the miner's term ore, whilst others are not. In this section dealing with the ores and their associates, we shall therefore describe these secondary or associated minerals immediately after the metallic ores from which thay have been derived.

This method of grouping minerals, according to the metals which they contain, differs from the classification usually adopted by mineralogists, in which minerals containing the same acid radicle are grouped together. Thus in the text-books on mineralogy, cuprite is placed amongst the oxides and malachite amongst the carbonates: but in this book these minerals will be considered in connection with the ores of

copper from which they have been derived, and they are represented all together on the same plate (plate 13).

In this division of our classification we may also conveniently place sulphur, since this is used for the same purposes as are the sulphur-containing metallic minerals iron-pyrites and marcasite, and further it is sometimes spoken of as an ore.

As an appendix to the ores of iron we shall treat of meteoric iron and meteorites. These bodies represent extra-terrestrial rock masses and their consideration strictly belongs to the subject of petrology, but since many points of interest are presented by their origin and their characters they may find a place in this volume.

The minerals with which we shall deal in this section are then, with the exception of sulphur, the heavy metals and their more important compounds.

Ore-deposits. — The minerals which are of value to the miner as ores occur in the earth's crust under almost the same conditions as most other minerals: but on account of their economic importance their modes of occurrence have been much more extensively studied and numerous theories to explain their origin have been propounded. It would be out of place here to give a detailed account of the important subject of ore-deposits, and we shall only briefly note the more important types and indicate how they may have been formed.

Some ores are found in connection with eruptive rock masses, which have consolidated from molten material erupted from unknown depths of the earth; others are found interbedded in sedimentary rocks, which have been deposited in water; others again, are found filling crevices and cavities in the rocks of the earth's crust; and some occur as water-worn fragments with sand and pebbles in rivers gravels.

All eruptive rocks contain small amounts of heavy metals, and in general the amount is greater in those rocks containing less silica, that is, in the more basic rocks. As a rule, the heavy metals are here present in combination with oxygen or acids and are uniformly distributed throughout the whole rock mass. Of the minerals so present in igneous rocks, magnetite is the most prominent, small amounts of which are invariably present in such a rock as basalt. Sometimes these metalliferous constituents of the igneous magma have been collected together or concentrated in certain parts of the mass, by a process known as magmatic differentiation. Examples of this class of ore-deposit are furnished by the separation of magnetite in syenite, of titaniferous iron-ore in gabbro, and of pyrrhotite and other sulphides in gabbro (see under magnetite and pyrrhotite).

Ore-deposits occurring in sedimentary, or stratified, rocks are called bedded deposits. These ore-bearing sediments may be of considerable horizontal extent but of little thickness, as in the well-known copper-slate or "Kupferschiefer" of Thuringia; or they may be of limited extent horizontally and of considerable thickness, as in deposits of haematite iron-ore. In such cases as these the ore may have been deposited at the same time as the sediment forming the mass of the rock, the two being intimately intermixed. Or again, the ore may occur entirely in a separate bed or stratum with barren rock above and below.

The deposition of iron-ochre around a chalybeate spring is a process which can be observed any day, and it is probable that many important deposits of iron ore have had such an origin. In a bog-iron-ore the material presents much the same characters as when originally deposited; but in the course of time it may be considerably modified by the processes which take place in the earth's crust. For example, by heat and pressure, due to contact with a mass of igneous rock, the iron ore may become dehydrated and converted into magnetite. Ore-deposits which have been profoundly modified in

character by contact with igneous masses in this way are called contact metamorphic deposits. The alteration or metamorphism is not confined to the ore, but affects also the surrounding rocks. Thus, limestone is converted into marble; special minerals, called contact minerals, such as spinel, garnet, idocrase and wollastonite, are developed in clayey limestone; while in clay-slates, andalusite is formed as a new mineral.

The clay-iron-stone which is so abundant in the coal-measures is a sedimentary deposit, and was without doubt originally deposited as such (iron carbonate) with intermixed clay and coal. Certain deposits of limonite (e. g. the "minettes" of Luxemburg) and of red-iron-ore (haematite) are also probably true sedimentary deposits; and perhaps also the sandstone with grains of galena which occurs near Mechernich in Rhenish Prussia, although the density and the distribution of the grains appear to contradict this. The copper ores in the "Kupferschiefer" of Thuringia, have been considered by some authorities to be original sedimentary deposits, whilst others assert that the ore has been introduced into the beds at a later date. The pyrites deposits at Rio Tinto in Spain and at Goslar in the Harz Mountains have all the appearances of sedimentary deposits, being faulted and tilted in the same manner as are the sedimentary rocks with which they are interbedded.

In other sedimentary rocks, which in most cases have been deposited in the open sea, the ores have been introduced at a date subsequent to that at which the rocks were deposited; and we find the ore taking the place of the rock. This is especially the case with limestones, which are often replaced by ores of iron or of zinc. Calcium carbonate is capable of precipitating heavy metals from their solutions, an equivalent amount of calcium at the same time passing into solution. When, therefore, an underground water containing metallic salts in solution comes into contact with a bed of limestone, the metal is deposited and the limestone is removed. The state in which the metal is deposited, or the compound of the metal actually formed, will depend on the nature of the metal: in general, it is the carbonate of the metal that will be deposited and will remain in the deposit, providing that it is not readily oxidizable. Under such conditions zinc would be deposited as carbonate, but with iron and manganese, carbonates would only be formed in the absence of oxidizing agents; more often iron and manganese would be deposited as oxides or hydroxides, such as haematite, limonite, pyrolusite, psilomelane, etc. The solutions which have produced these changes in beds of limestone may have derived their metallic salts from a bedded ore-deposit included in strata overlying the limestone (an example of which is mentioned under calamine) or from some other neighbouring and preexisting ore-deposit which had been subjected to the action of percolating waters; or the solution of the metallic salts may have arisen from unknown depths in the earth's crust.

In some instances the metallic constituents may have been originally present in the limestone itself, but uniformly distributed through the whole mass in relatively very small quantity. By the action of carbonated waters the calcium carbonate of the limestone may be dissolved and removed, leaving the oxidized metallic compounds behind in a concentrated form, that is as a deposit of ore. Deposits of iron ore and of manganese ore may in some instances have been formed in this manner. The weathering of some other rocks may give rise to a concentration of ores in the manner just described for limestones.

The concentration of gold, platinum, tin ore, and precious stones in alluvial deposits is also a result of the processes of weathering. The mother-rock which contained these valuable minerals in only relatively small amounts became disintegrated by chemical and mechanical means, and a large portion of the lighter material carried away by

running water. In this way the heavier minerals come to be collected in the gravels of the streams in the immediate neighbourhood of the mother-rock. Deposits of this kind are known as placers when they contain gold, tin-stone and other valuable minerals, and as gem-gravels when they contain precious stones.

Of special importance are those deposits of ores and minerals known as *mineral-veins* or *lodes*. These are fissures, usually steeply inclined, in the rocks of the earth's crust, which have been filled with mineral matter. Whilst the minerals in bedded and other deposits are usually granular and massive, those found in veins are often well crystallized; and indeed most of the finest crystals and specimens to be seen in mineral collections have been taken from veins or other cavities. Several different types of veins may be distinguished. Some contain only minerals which are of no value to the miner, whilst others may be composed largely of valuable ore. Sometimes the whole vein may be filled by a mineral of one kind, but more often several minerals occur together in the same vein. In the latter case there is usually a symmetrical arrangement of the material, the layers of material on one wall of the vein being repeated in the same order on the other wall.

The mode of formation of mineral-veins and the origin of the heavy metals contained in the ores have been the subject of much study and controversy, and even at the present day such questions are far from being completely and satisfactorily settled. In very many cases mineral-veins occur in direct connection with masses of eruptive rock or at least in the immediate vicinity of such masses. There can thus be little doubt but that there is some essential connection between the formation of mineral-veins and the eruption of molten magmas into the rocks of the earth's crust. In some instances it is clear that the metals must have been brought up from great depths by solutions or vapours, either during or shortly after the eruption of the igneous magma, and further that the solutions or vapours contained certain elements (chlorine, fluorine and boron) which played an important part in the formation of the minerals. The solutions or vapours would penetrate, not only into the open fissures, but also to a certain extent into the surrounding rocks, and chemical changes would be brought about and some new mineral matter deposited. Examples of an action of this kind are to be seen in the veins of gold ore in the southern slopes of the Carpathians (see under gold) and in the copper veins of Lake Superior in North America. In some other instances we are driven to the conclusion that the heavy metals must have been brought up from the earth's interior by the igneous material itself: and that by the subsequent weathering of the rock they have been leached out and re-deposited in crevices in the rock. The metals may have been present as traces in the silicates (olivine, mica, augite, etc.) composing the rock, and have been set free when these minerals were decomposed. An example of this is perhaps afforded by the veins of manganese ore which penetrate a porphyritic rock at Ilfeld in the Harz Mountains; it having been determined that manganese is present in small amount in the porphyritic rock itself. Whether any particular mineral-vein has originated in either of these or in some other way would be difficult to determine. In any case the processes are obscure and complex. Solutions heavily charged with mineral matter arising from great depths may become mixed with surface waters which have obtained their soluble constituents by the weathering of superficial rocks; and by the interaction of these solutions in the fissures or by the presence of each alternately it is possible that different types of deposits may be formed in the same vein.

Mineral-veins are, however, not invariably found in association with igneous rocks: they also occur, quite independently of these, in sedimentary rocks. As an

example may be mentioned the veins of cobalt ore in the "Kupferschiefer" (see under bornite).

When the overlying rocks have been removed by denudation, a mineral-vein will become exposed to the action of weathering processes, and several secondary minerals, which are not present in the deeper portions of the vein, will be formed. By the action of water containing oxygen and carbonic acid in solution the original minerals of the vein will be decomposed, a portion of their material being removed in solution, and another portion giving rise to compounds which are stable under the new conditions nearer the surface. Thus with iron compounds, such as iron-pyrites, the decomposition will result in the formation of limonite: metallic ores of copper will be altered to malachite, chessylite, cuprite and native copper; lead ores to cerussite and anglesite. These secondary minerals are those mentioned at the commencement of this section as the associates of the metallic ores. They are especially characteristic of the upper or oxidized portions of mineral-veins; and as iron is often a common constituent, they are usually much mixed with limonite (brown iron-ore). For this reason the outcrop of a lode at the earth's surface has usually a rusty and cellular appearance, and this ferruginous capping of the lode is known to the German miners as the "eiserner Hut" (iron hat) and to Cornish miners as the gossan. In this connection may be quoted an English equivalent of an old German saying:

"A lode that wears no iron hat
is never likely to be fat".

Gold.

From the earliest times gold has been used for personal ornaments, and it has long been employed as a standard of exchange. In the tombs of the Egyptian kings, dating back two or three thousand years before Christ, valuable gold ornaments and objects of various kinds have been found; these include armlets, clasps, weapons, chains with golden bees and scarabs for wearing as amulets, and small boats made of gold and silver.

That extensive use was made of gold in byegone ages is especially seen from the results of the excavations made by Heinrich Schliemann on the site of the ancient city of Troy. At the time of the second settlement, about 4000 B. C. and long before the Troy of Homer, the "great treasure" was hidden away in a silver vase and remained lost to sight for thousands of years. In this vase alone were found two gold cups, two large gold diadems, a frontlet, six armlets, four ear-pendants, fifty-six ear-rings and 8750 beads of gold. Belonging to the same period there were also found many other gold ornaments, needles, cups, goblets and vases, as well as bars of gold notched on one side which had perhaps been used as money. These ornaments and utensils are of beaten gold, and the handles of the cups are in some cases riveted and in others soldered. Even at this very early date the art of working gold had reached an advanced stage, though the later ornaments from Mycenae show a still greater advance. The large gold diadem carries a horizontal chain twenty inches (52 cm.) in length from which hang ninety chains of varying lengths, and on these scale-shaped plates are arranged, the whole design being simple but very effective. The gold of these articles has a fineness of 23, 20 or 18 carats; of the 18 carat gold, or electrum, cups were made. It is certain

that the gold was not alloyed with silver, but was used in the condition in which it had been found.

In the tombs of the ancient Grecian city of Mycenae, dating back two thousand years before Christ, Schliemann's excavations resulted in the discovery of a number of discs of gold impressed with patterns, large gold diadems, gold goblets and cups ornamented with the figures of animals (fig. 105), finger-rings, hair-pins, ear-pendants, armlets, buckles, and masks of sheet gold (fig. 106). In one tomb was found a child's body completely encased in sheet gold.

The kings of Assyria, Babylonia and Persia are said to have accumulated vast treasures of gold in their palaces; their temples were richly decorated with gold,

Fig. 105.
Gold cups from a tomb near Amyclae, Greece.

Fig. 106.
Gold mask from Mycenae, Greece.

and contained images of their gods wrought in pure gold. It is related that at the sacking of Nineveh such was the amount of gold and silver taken that a thousand camels were needed to convey the treasure to Babylon and Egbatana.

It is also said that Abraham had much gold, and that Solomon's ships brought large quantities of gold from the land of Ophir; but it would seem that later additions to the ancient writings have largely exaggerated the amount of gold which Solomon possessed and the richness of his temples. Ophir was probably an important trade centre in Arabia through which valuable goods, not necessarily gold, largely passed. In ancient times gold was compared with the sun, and the Hebrew name "sahab" for gold signifies "to shine as the sun"; to the Assyrians gold signified the colour of the sun, and the alchemists of later times gave to gold the symbol of the sun.

Other peoples of less cultured nations have also used gold for purposes of personal ornament. In the prehistoric graves of the Tchudi armlets ornamented with lizard's heads have been found, and the aborigines of the new world wore gold plates in holes bored through the nose.

That gold has been so generally used for ornaments since the earliest times is readily accounted for by its mode of occurrence and its characters. It is found widely distributed in the free state in the beds of streams and rivers, it retains untarnished its colour and lustre, and it can be readily worked; being the most malleable of metals, it can be readily hammered out into scales or drawn into fine wire.

Gold as it occurs in nature is never quite pure, but is always alloyed with variable amounts of silver. This fact was mentioned long ago by Pliny, who gave the proportion of gold to silver as being commonly 10:1 or as 8:1; the most valuable metal contained only a thirty-sixth part by weight of silver, whilst the least valuable contained four parts of gold with one of silver. The latter was distinguished by him as electrum, on account of its pale yellow colour, resembling that of amber which was known to the Greeks as electron. This has been completely confirmed by more recent investigations.

It has been shown that the purest of native gold always contains at least 1—2 per cent. of silver, and that in most cases 5—10 per cent. of silver is present, whilst for certain occurrences, for example in Transylvania, it reaches 25—30 per cent.

Correlated with the variation in the amount of silver present in the native metal there is a corresponding variation in the colour and specific gravity. Gold with little silver shows the deeper shade of gold-yellow characteristic of pure gold (as in figs. 6 and 7 of plate 5, representing gold from California, containing 7—10 per cent. of silver). On the other hand, when much silver is present the gold-yellow colour is much paler (as in figs. 4 and 5 of the same plate, representing gold from Transylvania, containing about 30 per cent. of silver). The specific gravity of the purest native gold is 19, that is to say, the native metal is nineteen times as heavy as an equal volume of water: as the silver increases in amount the specific gravity correspondingly decreases, and may be as low as 15·6. Pure gold melts at a temperature of 1035° Centigrade.

The hardness of pure gold is quite low, lying between that of gypsum and calcite, that is H. $= 2\frac{1}{2}$—3 on the scale. The pure metal is thus too soft to be used for coins and for those ornamental articles, such as watch-chains, which are exposed to wear and tear. In order to increase the hardness of the gold it is melted with copper or less often with silver, the process of alloying with copper being known as "red caratizing" and with silver as "white caratizing". The "fineness" of this alloy is measured by the amount of gold present, and on this depends its value. In England this is expressed as so many carats, but this is not to be confused with a carat-weight, which unfortunately is a variable quantity. Taking pure gold as being of a fineness of twenty-four carats, an alloy containing half its weight of gold is said to have a fineness of twelve carats, and so on according to the number of the twenty-four parts which consist of pure gold. The English gold coinage has a fineness of twenty-two carats, that is, it consists of $\frac{22}{24}$ or eleven-twelfths of fine gold. A sovereign piece weighs 123·274 grains, of which 113 grains are gold. In Germany the fineness is expressed far more simply and rationally by stating how many parts of gold are present in 1000 parts of the mixture of metals. The German gold coinage has a fineness of 900, that is, 1000 parts of the alloy contain 900 parts of gold (90 per cent.) and 100 parts of copper. A ten-mark piece weighs 3·982 grams and therefore contains 3·585 grams of gold and 0·397 grams of copper; its specific gravity is 17·2.

For the purpose of testing the fineness of gold alloys the jeweller uses a test-stone, which is a compact, black variety of quartz known as lydian-stone. By rubbing the metal on the stone the streak of the former is obtained on the latter, and from the depth of colour of this, either before or after treating with acids, he is able to judge approximately the fineness of the gold, though of course only on the surface of the article so tested.

Gold is unattacked by any single acid, but is readily dissolved by aqua regia, a mixture of nitric and hydrochloric acids; other mixtures of acids which liberate chlorine also dissolve the metal, and it is soluble to a very slight extent in a solution of common salt. It is present as a minute trace in the salt water of the ocean, and recent determinations made with sea-water from the Australian coast show that a cubic mile of sea-water contains in solution 130—260 tons of gold. Attempts have been made to extract gold from sea-water on a large scale, but so far without any results of commercial importance.

Another important solvent of gold is a dilute solution of potassium cyanide, which is now extensively used for extracting metallic gold from its ores. From the solution so obtained the gold is separated by electrolysis. This is known as the cyanide

process, and it has now practically replaced other processes formerly employed for the extraction of gold.

Gold readily unites with mercury to form an amalgam, and this is also a property of the metal which has been extensively used for its extraction from the crushed ore or from auriferous sands. This method was used by the Romans and is still employed in the treatment of the finest gold-bearing sands. On heating the amalgam so obtained, the mercury is volatilized and the gold remains behind.

Although gold usually occurs in nature in the metallic or native state, yet it is often so finely divided that it cannot be separated from other minerals by purely mechanical means. It has therefore been necessary to resort to either the cyanide or amalgamation process in order to win the more finely divided metal. The coarser particles in a river gravel can be collected by a simple process of washing, by which the lighter minerals are carried away by a current of water, while the heavier gold remains behind.

When gold occurs embedded in the solid rock, it may be distinguished as rock-gold or *vein-gold* (plate 5, figs. 11, 13); but when it occurs as loose fragments with pebbles and sand in the beds of rivers and streams or in other alluvial deposits, it is distinguished as *alluvial gold* (plate 5, figs. 6, 7), or as gold-sand or washed gold. In all gold-yielding countries the deposits of alluvial gold, being more easily worked, are first exhausted before the solid rocks themselves are attacked.

In most cases rock-gold occurs in the quartz of veins which penetrate the ancient crystalline rocks (gneiss and mica-schist), deep-seated igneous rocks (granite, etc.), or volcanic rocks (especially trachyte). The quartz of such veins is called gold-quartz or auriferous quartz, and the gold it contains is in most cases not uniformly distributed throughout the mass, but collected in veins and strings (plate 5, fig. 13). Only rarely does the gold occur in relatively large masses, as in the specimen represented in the figure; more often it is present only as minute scales or as mere dust and is not visible to the unaided eye. In rare instances, however, large masses of gold have been found embedded in the solid rock; the largest on record is a mass weighing 43·08 kilograms (95 pounds avoirdupois) raised from the Monumental mine in Sierra County, California. Another unusually rich mass of native gold taken from the solid rock was one containing 57·7 kilograms (according to other accounts, 67·7 kilograms) of fine gold, which was found in the Muszari mine at Brad on the western side of the Csetras Mountains in Transylvania: the gold had the form of small platy crystals aggregated in mossy groups, and was associated with crystals of zinc-blende and marcasite on quartz.

The mineral most frequently associated with gold in quartz is iron-pyrites, which itself contains small amounts of gold. With the weathering of the iron-pyrites and the formation of limonite the gold it contained is liberated (plate 5, fig. 14). In this way free gold occurs in the oxidized ferruginous gossan in the upper part of mineral lodes, since in most cases iron-pyrites contains small amounts of gold. In such cases, however, the gold is usually so finely divided that it can only be extracted by amalgamation or by special metallurgical processes.

Distinctly developed crystalline forms are rarely exhibited by the gold which occurs embedded in quartz. Crystals may be sometimes found in cavities in the quartz or in the adjacent rock, but these crystals of gold are usually much distorted and their form obscured by twinning.

Three crystals of gold are represented in plate 5 (figs. 1—3); they are not large and finely developed as are the crystals of many other minerals, but they are quite good crystals for gold, which indeed only exceptionally occurs as distinct crystals. Fig. 1

shows a small sharp crystal, a cube with small faces of the octahedron, from Vöröspatak in Transylvania. Crystals from this Hungarian locality rarely exceed 3 mm. across. Fig. 2 shows a group of cubo-octahedra from Mount Ararat in Victoria; and fig. 3 a rhombic-dodecahedron from Ballarat, Victoria: the last two crystals from Australia are probably from alluvial deposits and not from a quartz-vein.

A pretty specimen of crystallized leaf-gold, belonging to the collection of Mr. Gustav Seligmann of Coblenz, is represented in its natural size in plate 5, fig. 4, and enlarged in plate 7, figs. 1 *a* and *b*. Its glittering lustre and the delicate patterns on its surface immediately attract attention, but unfortunately the beauty of the markings is not adequately brought out in the figures. It may, however, be seen that both surfaces of the plate carry numerous small, triangular pyramidal elevations, which are truncated by triangular facets parallel to the plane of the plate, and that these are all arranged in parallel position. The triangular facets are the faces of the octahedron, and the faces forming the sides of the small pyramids are those of an icositetrahedron. The hexagonal outlines of the plate are bounded by other narrow faces of the icositetrahedron. The whole plate is thus built up of a number of small crystals arranged in parallel position, but these crystals present a distorted or flattened form owing to their greater extension in the surface of the plate than perpendicular thereto. It may be further noticed (as more clearly seen in fig. 1 *b*) that the triangular markings on one portion of the plate are placed in a reverse direction with respect to the triangles on the other portion: this reversal in direction is due to twinning on the octahedral face parallel to the plate, the two twinned portions being combined along a plane perpendicular to the twin-plane.

Another, but less perfect, specimen of crystallized leaf-gold is represented in fig. 5 of the same plate. Other specimens of the same kind exhibit six-rayed patterns of golden stars, or delicate networks of various forms, which at first sight might be thought to be artificial gold brocade. Such specimens of gold afford excellent examples of the regularity and complexity of crystalline growth. They were exhaustively studied crystallographically by the late Professor G. vom Rath and the specimens he described are exhibited in the mineralogical museum at Bonn.

Besides the more regularly formed crystals and the crystallized plates already described, gold is also, but less frequently, found in wiry forms (plate 5, fig. 14); these also are built up of small crystals with perfect regularity of arrangement, but they are not so easy to decipher.

The gold-bearing rocks when exposed to the action of weathering agents become broken down and their materials carried away and sorted by running water. The gold being much heavier is not carried far from its source, whilst the lighter quartz is removed as sand and pebbles. In this way, during the course of ages, the gold set free from the mother-rock by weathering becomes accumulated in the beds of streams and in river gravels, and these secondary deposits are thus far richer in gold than are the rocks from which they have been derived. Not only are these deposits relatively richer in gold, but being incoherent they are more easily worked and the gold is readily won from them by a simple process of washing. It is therefore natural that in all gold-yielding countries these alluvial deposits were the first to be worked, leaving until later the more laborious and costly work involved in extracting gold from the mother-rock. At the present day the amount of gold extracted from the solid rock is far in excess of that won from alluvial deposits.

The free gold found in alluvial deposits is very variable in the external form of its particles; it does not present the rounded forms of the pebbles of quartz and

rocks with which it is associated. This is readily accounted for by the toughness and malleability of the material, which will yield more to blows and to pressure than to a rubbing and rolling action; there will thus be a tendency for the particles of water-worn gold to assume the form of scales rather than of rounded grains and pebbles. In most cases, by the battering of the pebbles in the running water, the gold has become completely isolated from the quartz, and it is not often that the two minerals are found intimately mixed together in the same pebble or fragment. An instance of this kind is seen in the magnificent specimen represented in plate 5, fig. 12, a specimen from the gold-washings in the Ural Mountains which was bequeathed by Queen Olga to the Natural History Museum at Stuttgart. The quartz, though much fractured, has here been held together by the large amount of gold which penetrates the whole mass as a coherent network. More often the brittle quartz would be shattered and broken away, whi'e the films and strings of malleable gold would be more closely pressed together. In this way small fragments of quartz may still remain embedded in the mass of gold, as seen in fig. 8, representing a piece of alluvial gold from Mexico (or perhaps from California, which until 1848 formed a part of Mexico). It is, however, quite possible, that in this specimen the single grains of quartz, which appear to be water-worn, may have later become embedded in the mass of gold: the clear spaces in the figure are holes through the mass from which quartz grains have disappeared.

Figs. 6, 7 and 9 of the same plate represent specimens of alluvial gold entirely free from quartz: the two first are from California, and the last with a blistery surface and a thin brown coating is from Dutch Guiana. The specimens here figured are of relatively large size, and such larger pieces are called "nuggets". More often the pieces of gold found in alluvial deposits are much smaller, being only scales or grains. The largest nugget, or mass of alluvial gold, that has been found was one weighing 70·9 kilograms (156 pounds avoirdupois) from Victoria; and the largest from the Ural Mountains was one of 36 kilograms, found near Miask in 1842.

No other precious metal is so widely distributed as gold, and at the same time no other has been so eagerly sought. For long ages the more accessible and easily worked alluvial deposits of gold occurring in civilized countries have been exploited, with the result that such deposits are now practically exhausted. For this reason the largest production of alluvial gold at the present day is from districts bordering on unexplored regions, as for example in Alaska and British Columbia. The greater part of the gold now obtained is, however, extracted by new methods from solid rocks in which it is present in only relatively small amounts, as for example in the Transvaal.

In the following paragraphs we shall give an account of the occurrences of gold at the various localities where it has been found. Here, as throughout the whole volume, particulars concerning the localities of different minerals are largely taken from Professor C. Hintze's "Handbuch der Mineralogie", though use has also been made of some other sources of information. This branch of the subject is exhaustively treated by Professor Hintze, and in his treatise he has collected together all the available information of scientific value: to this work, then, the student is referred for further details, especially with respect to the localities of lesser importance, which are not mentioned in the present volume. In the statement of the localities of the specimens figured on the accompanying plates special efforts have been made to give these as accurately as possible.

In *Germany*, the principal gold-bearing river is the Rhine, from its confluence with the Aar (itself a gold-bearing river in Switzerland) downwards. Most of the Rhine gold has long ago been won, and the old washings were often at spots where the river

was breaking down its banks. The principal washings were between Kehl and Daxlanden, and especially near Helmlingen, in Baden. In 1838 the number of gold-washings in Baden still numbered four hundred; during the thirty years from 1804 to 1834 the total yield was rather over three hundredweights and of a value of 209,075 gulden. It was estimated by the French geologist Daubrée that the Rhine between Basel and Mannheim had yielded gold to the value of 170 million francs. The largest nugget known from Germany weighed 66 grams, and was found in 1826 in the Grossbach, a stream running into the Moselle (a tributary of the Rhine) near Enkirch.

From the Eder, a tributary of the Fulda, gold is said to have been washed in the time of Charles the Great. The first ducats of Eder gold were coined in 1677 by the landgrave Charles and bore the inscription "Moneta prima aurea Aederae Aurifluae": on the reverse side was a view of the Eder with the Guldensberg and Felsberg and a figure of the river-god. In 1731 ducats of Eder gold were coined under the landgrave Friedrich I, King of Sweden, which were inscribed "Eddergold" (fig. 107): and those coined in 1775 under landgrave Friedrich II bore on the reverse side the inscription "Sic. Fulg. Litora. Adranae. Auri. Fluae." (fig. 108). In the year 1832 a Hessian and Waldeck company with a capital of 400,000 thalers was formed for the purpose of winning gold from the Eder, the work being carried on under the direction of L. von Eschwege, who had gained considerable experience in the Brazilian gold-fields. The production in 1833 amounted to 18 lot $1^1/_4$ quent, equal to 300 grams; and two years later all the capital had been expended. The peasants, however, continued washing for gold until the middle of the nineteenth century, but with no very profitable results.

Fig. 107.

Fig. 108.

Ducats made of gold from the river Eder, Germany.

Washing for gold has also been carried on in several rivers in Bavaria (the Donau, Salznach, Alz, Inn, Isar and Ammer, and several streams in the Fichtelgebirge), in Thuringia, and in Silesia. Of greater importance were the arsenic ores of Reichenstein in Silesia, which contained 3—4 grams of gold to the ton of ore: from this gold was made the font of the Royal House of Germany. Most of the gold now won in Germany is extracted from metallic ores, such as galena, copper-pyrites, iron-pyrites and zinc-blende, which usually contain traces of the precious metal: some of these ores are however imported, and are not of German origin.

In the *British Isles*, gold has been found at several localities, and has been worked on a small scale ever since the time of the Romans and no doubt also before them, since gold ornaments were worn by the Ancient Britons. Small quantities were formerly collected in the washings for stream-tin in Cornwall, especially in the Carnon Valley in Feock parish, near Falmouth; here several small nuggets have been found, the largest weighing 2 ozs. 3 dwts. (67 grams). In Wales, more particularly in the neighbourhood of Dolgelly in Merionethshire, gold occurs, sometimes in considerable quantity, in quartz-veins together with galena, copper-pyrites, iron-pyrites and zinc-blende. In 1904 the output of Welsh gold was valued at £73,925. In Scotland, gold was formerly found in considerable amount in the Leadhills district, and quite extensive workings were carried on there in the sixteenth century; a nugget weighing as much as 30 ounces has been recorded. Sutherland and Perthshire have also yielded alluvial gold. In Ireland, alluvial gold was discovered in 1795 in the neighbourhood of Croghan Kinshela in County Wicklow, and for a short time a considerable amount was collected: the largest nugget found weighed about 22 ounces.

In the eastern *Alps* of Salzburg and Carinthia considerable amounts of gold were formerly won, but at the present time workings on a small scale are carried on only at the Goldberg near Rauris and at the Rathausberg near Gastein. In the western Alps, Dauphiné is a district which has formerly yielded gold. The Romans obtained large quantities of gold from *Spain*, but the supply is now exhausted. Pliny refers to Asturia as the richest gold-field in the world, and he placed the value of the gold annually exported to Rome at £20,000.

Hungary is the only European country which, at the present day, is comparatively rich in gold, and the portion of this country in which it occurs is along the inner side of the great arc of the Carpathians, especially the eastern portion in Transylvania. The veins of gold-bearing quartz here intersect trachytic volcanic rocks of Tertiary age, or other rocks in the immediate neighbourhood of these volcanic rocks. At Schemnitz in Hungary, where mining is said to have been carried on before the Christian era, the ore in the veins consists largely of auriferous and argentiferous galena, zinc-blende, copper-pyrites and iron-pyrites with very little free gold. The same is also the case at Kremnitz in Hungary. On the other hand, the mines in the neighbourhood of Brad in Transylvania are unusually rich in free and visible gold. This small mining town is situated on the western borders of the Csetras Mountains, and the richest mine in the district is, at the present time, the Muszari mine. The veins are richer in gold at those points where they are crossed by other veins. The gold occurs in the form of plates and scales and is associated with auriferous iron-pyrites, black zinc-blende and other ores as well as the ubiquitous quartz. On an average, the ore contains 1000 grams of gold to the ton, while in places it yields five times this amount. It was the Muszari mine that yielded the exceptionally rich mass of gold mentioned above. In the year 1895 the production of this mine amounted to 732 kilograms of bar gold (i. e. gold containing some silver). Rich gold ores have also been obtained from the mines near the village of Boicza; and in the spring of 1897 the ore yielded 2050 grams of bar gold per ton, this consisting of 668 parts of fine gold with 310 parts of silver. The total production for the year 1895 amounted to 294 kilograms of gold and 166·7 kilograms of silver.

The best known of the Transylvanian gold localities is that of Vöröspatak, it being here that the best crystals are found, a few examples of which are represented in plate 5, figs. 1, 4, 5 and 11. The crystals are found either attached to the walls of drusy cavities, or they are embedded in the clayey material filling these cavities; in the latter case, the crystals or aggregates of crystals are freely developed on all sides, and they then sometimes exhibit more regular cubic forms. Usually, however, the crystals are much distorted and twinned, the delicately crystallized leaf-gold described above being especially characteristic of this locality. The leaf-gold found embedded in the clay is sometimes rolled up like paper or in concentric shells like an onion. Again, some of the distorted crystals are elongated like wire with a square cross-section, bearing on the free end a platy crystal. The distorted crystals of gold contained in the drusy cavities have often been considered to be of secondary origin, the finely divided gold contained in the rock and in the accompanying iron-pyrites being taken up in solution and re-crystallized in the cavities. The production at Vöröspatak is small compared with that of the other Transylvanian localities mentioned above: yet in this district there are 172 small workings, and the water from five reservoirs drives over 6000 stamps used for crushing the ore. The gold is so finely divided in the rock that it is not visible to the naked eye.

Bosnia is another of the countries from which the Romans obtained gold. Rich gold-washings were worked in the district lying to the north-west of Sarajevo, namely

in the upper courses of the Vrbas, in the valley of the Lasva, and in the neighbourhood of Fojnica.

In the *Russian Empire*, gold occurs in the Urals, the Altai, Transbaikalia, in governments Olonets and Yeniseisk, in Kamchatka, and on the east coast of Siberia opposite Alaska. Native gold is found embedded in the solid rock at several places in the Ural Mountains, and indeed vein-gold was here discovered (in 1745) before the alluvial gold. For instance, in the district around Beresovsk, near Ekaterinburg on the eastern side of the Urals, gold occurs with auriferous iron-pyrites and copper-pyrites in quartz-veins which penetrate or are closely associated with a granitic rock called beresite. These veins of gold-quartz yield about 13 grams of gold per ton of ore. Of much greater importance are the widely distributed alluvial deposits on the eastern slopes of the Urals, especially around Bogoslovsk, Nizhne-Tagilsk, Beresovsk, Miask and Orenburg. The gold-bearing gravel rests directly on the ancient crystalline rocks, and is overlain by gravel, sand and turf of varying thickness up to twenty metres. The Uralian gold usually has the form of small grains and scales, sometimes of small rod-like particles, and rarely as crystals or large nuggets. A fine specimen is represented in plate 5, fig. 12, and mention has already been made (p. 77) of the largest mass found in the Urals. The content of silver is usually 6—8 per cent., though some grains contain as much as 16 per cent. and others as little as $\frac{1}{2}$ per cent. of silver. The gold-washings in the neighbourhood of Bissersk are of especial interest, since it was in these that diamonds were first discovered in the Urals. In some of the other washings, platinum occurs in association with the gold. The production of gold from the Urals in the year 1899 was 10,448 kilograms.

The gold of the Altai Mountains in Siberia contains much silver and is consequently of a pale brass-yellow colour; it is the variety known as electrum. At Zmeinogorsk (the German name for which is Schlangenberg) it occurs on the surface of the rock as thin plates or as a mossy aggregation of minute scales, and is also found in alluvial deposits. In the gold-fields of Eastern Siberia, alluvial deposits are worked, and these account for 60 per cent. of the production of the Russian Empire.

California is the most famous and richest of all gold-bearing countries. Alluvial deposits have been worked here since 1848, though before that date a few pieces of gold had been picked up on the surface. Since then fabulous amounts of gold have been obtained; during the last fifty years the total production is valued at 260 million pounds sterling, or a yearly average of $5\frac{1}{5}$ million pounds. The yield during the first thirty years was above this average, while at the present time it amounts to about three million pounds sterling per annum. This decrease in the production is explained by the fact that the richer alluvial deposits were first worked, and afterwards the gold-rock was exploited. The gold-bearing gravels of California occur on the western side of the Sierra Nevada for a distance of 700 miles; they lie in the valleys of the present rivers and also in old river valleys of Tertiary age, the latter having since been covered up by outpourings of volcanic lava (basalt) and their tuffs. The deposits in the present river valleys are now almost exhausted: those lying higher up the valleys were formerly worked by the process of hydraulic mining. The gravel was washed away by enormous jets of water which was conveyed under pressure from considerable distances. In this way, at a cost of two million dollars, almost 35 million cubic metres of débris was removed, and this enormous amount of material was carried by the water to the lower lying land, where if spread out uniformly to a depth of one metre it would have covered 35 square kilometres of county. Naturally the land owners objected to this, and since 1887 this method of working has been prohibited by law. Fairly large nuggets of gold were sometimes found in these alluvial deposits (plate 5, figs. 6 and 7), but usually

only very small grains and minute scales were present. The metal contains about 10 per cent. of silver.

At the present time most of the Californian gold is obtained by mining the quartz-veins in which the gold is embedded (plate 5, fig. 13) in association with auriferous iron-pyrites. Most of the gold is present in the quartz in a very finely divided state and is not visible to the naked eye; it also often occurs only in the iron-pyrites, so that in many mines there is no free gold. The average yield is 15 to 20 grams per ton of ore. The extensive system of veins of gold-quartz lies on the western slopes of the Sierra Nevada: they are associated with granitic rocks, which are widely distributed in this region, and to which the veins owe their origin. The main vein or "mother vein" is really a system of parallel veins extending unbroken for a distance of seventy-five miles; and it is along these that the richest mines are situated.

The regions further north on the west coast of North America are also rich in gold, especially in *British Columbia* and *Alaska*. Rich alluvial deposits were discovered here during the past decade, and doubtless still more remain to be found in these little-explored countries. The richest gold-field is on the Klondike river, a tributary of the Yukon river in British Columbia, situated not far from Fort Reliance in latitude 64° N. and longitude 139° W. The richest spot, in the Bonanza Creek, now called the El Dorado Creek, was discovered in the autumn of 1896, when thousands of searchers for gold from all lands rushed in and a new town, Dawson City, rapidly sprung up. Here, with a climate not of the best and a temperature in winter of — 55° C., the population increased in two years to 20,000. The gold-bearing veins of quartz are here, as elsewhere, associated with granite, which breaks through the crystalline schists of the region; and the gold-bearing alluvial deposits lie directly on the crystalline rocks. The deposits of sand and pebbles attain a thickness of ten feet and stretch for miles along the valleys. On the average the yield of gold per cubic yard of gravel is of the value of £5 to £6, and a foot of ground along the valley will yield about £200. These gravels are the richest that have been met with anywhere. The gold is comparatively coarse grained, the grains being the size of those of a coarse sand; and it contains on the average 75 per cent. of fine gold.

In very nearly the same latitude are the rich gold-sands discovered in the summer of 1899 on the sea-shore at Cape Nome in Alaska. These find their continuation across the Bering Sea on the east coast of Siberia.

Other states of the *United States* besides California are also rich in gold, and at the present day the production of California is surpassed by that of Colorado. The famous Comstock lode in the state of Nevada is the richest lode that has been worked in any part of the world. The ore which it yields contains native gold and several rich silver minerals (argentite, stephanite and polybasite). During the years 1860—1892 gold to the value of £30.000,000 and silver to the value of £45,000,000 were extracted. The lode has been worked along its whole length to a depth of a thousand yards, when springs of water with a temperature of 77° C. stopped further progress. The ores, together with quartz, fill a crevice in volcanic rocks of the andesitic type, and their materials were without doubt brought up from some deep-seated source subsequent to the eruption of the volcanic rock; and it is probable that mineral matter is still being brought up and deposited by the hot water which rises in the crevice.

Further to the south, native gold is found in Mexico, Central America, and several parts of *South America* as far as the Straits of Magellan. In Colombia and the northern part of the western coast the gold occurs in connection with granitic rocks, while further south in the Andes of Peru and Chile the veins are in connection with

younger volcanic rocks, such as liparite and andesite. In Chile some of the veins contain much iron-pyrites and copper-pyrites together with quartz and tourmaline: a specimen of free gold with limonite from the upper oxidized portion of such a vein is represented in plate 5, fig. 14. Alluvial deposits rich in gold are well represented in Brazil and further to the north in British and Dutch Guiana and Venezuela. In Dutch Guiana in addition to crystalline schists and granite there are basic eruptive rocks (dolerite) which are said to be auriferous. By the weathering of these rocks the gold is set free and collects in the rivers flowing northwards. The gold here has usually the form of small rods and grains, large nuggets being rare; one weighing 33 grams is represented in fig. 9 of plate 5. The production of Dutch Guiana reached a maximum in 1891 of 1237 kilograms.

The gold-fields of *Australia*, which were discovered at about the same time as those of California, have been extensively worked from the year 1851, and so continuous and abundant has been their yield that Australia (together with Tasmania and New Zealand) is one of the most important gold-producing countries of the world. All the states of the commonwealth are productive, and the gold occurs in the alluvial deposits of present or ancient rivers of Tertiary age (the latter being called "deep leads"), and in quartz-veins traversing archaean and palaeozoic rocks. In plate 5 are represented three specimens of gold from Victoria; fig. 10 of gold in fissured quartz, and figs. 2 and 3 of two isolated crystals.

In *Africa* by far the most important gold-field is the Witwatersrand, or the "Rand", in the Transvaal. Gold was discovered here in the year 1884, but under conditions quite different from those known in other parts of the world, so that there was not at first the enormous production of gold such as followed the discovery of the Californian alluvial deposits. The gold-bearing rock, known as "banket", is a conglomerate consisting of pebbles of quartz, the size of a pigeon's or hen's egg, cemented together with siliceous material. Throughout the rock are scattered microscopically small crystals or irregular grains of native gold and of auriferous iron-pyrites: only very exceptionally are the particles of gold large enough to be visible to the unaided eye. The conglomerates rest on beds of sandstone and are themselves overlain by thick sheets of amygdaloidal dolerite. This mode of occurrence of the gold renders its extraction all the more difficult: water and wood are scarce, though there is a sufficiency of coal in the district. The sinking and working of a mine therefore require the expenditure of a considerable amount of capital. The rock contains on an average 23 to 30 grams of gold per ton. In 1893, less than ten years after the first discovery, there were seventy gold mines on the Rand producing 45,980 kilograms of gold per annum. In 1898 the annual production had increased to 110,860 kilograms with a value of about fourteen million pounds sterling. During the Boer war the production fell off, but increased again in 1905 to 152,324 kilograms.

In *Egypt*, veins of gold-quartz traverse granite, which is also intersected by veins of quartz-porphyry and other eruptive rocks: when the latter are present in greater number, the neighbouring veins of quartz are richer in gold. The gold mines of Egypt were probably the earliest of any to be worked, and they must have supplied a large part of the gold used in ancient times.

Gold ores. — The only compounds of gold which occur in nature as minerals are various tellurides of gold usually with some other elements. The following are the more important.

Sylvanite (plate 8, fig. 1) is also known as "graphic tellurium" (German, Schrifterz) for the reason that the small rod-like crystals are often grouped on the surface of the rocky matrix in patterns bearing a certain resemblance to written characters. This

particular grouping of the crystals is due to twinning. The crystals are monoclinic but their forms cannot, as a rule, be made out by mere inspection. There is a perfect cleavage in one direction parallel to the clino-pinacoid, and it is usually on this face that the crystals are attached to the matrix. The mineral is steel-grey in colour with a bright metallic lustre, and contains approximately 30 per cent. of gold, 10 per cent. of silver, and 60 per cent. of tellurium.

Calaverite is distinguished from sylvanite by the absence of cleavage and by its pale brass-yellow colour. In these characters, and also in the metallic lustre, calaverite often presents a striking likeness to iron-pyrites, from which it may be readily distinguished by heating a fragment of the mineral on charcoal before the blowpipe, when calaverite (which contains 44 per cent. of gold with 56 per cent. of tellurium) will yield a bead of gold.

Nagyagite (plate 8, fig. 2) occurs in platy forms and has hence been called "foliated tellurium". Its colour is blackish lead-grey and the lustre is metallic. The chemical composition is complex, the mineral containing 6—8 % gold, 54—61 % lead, 15—32 % tellurium and some silver, antimony and sulphur.

These minerals occur in veins which usually penetrate acid volcanic rocks, and they have as yet been found at only a few localities, namely Nagyag and Offenbanya in Transylvania, Cripple Creek in Boulder County, Colorado, and Kalgoorlie in Western Australia. More especially at the two last mentioned localities they are of great importance, since here they have yielded large quantities of gold. At Kalgoorlie, tellurides of gold were discovered in 1896, when it was found that some of the material which had been thrown away on the waste heaps as comparatively worthless iron-pyrites was in reality calaverite containing no less than 44 per cent of gold! Since that date large quantities of tellurides have been mined, and the Kalgoorlie district is now the richest of the Australian gold-fields, yielding in fact as much gold as all the remaining gold-fields of Western Australia taken together. Unfortunately, the tellurides of gold are rather obscure minerals with no striking characteristics and they are not readily recognized. If carefully and diligently searched for by prospectors they will doubtless be found at other localities.

Besides the minerals mentioned above, which contain gold as an essential chemical constituent, there are several other metallic minerals in which gold is often present in traces and from which it may be profitably extracted. Such minerals are iron-pyrites, galena, copper-pyrites, zinc-blende, mispickel, stibnite, etc. All the gold produced in Germany is extracted from ores of this kind, some of the ores being of German origin and others imported.

The *applications of gold* are so well known that they need scarcely be mentioned here. By far the largest amount is coined; considerable amounts are made into plate, jewellery, watches, etc., and used for gilding; and some is employed in photography and for colouring porcelain. Quartz with gold embedded in it is sometimes cut and polished for ornamental purposes.

Coins and jewellery become gradually reduced in weight by wear, or they may be lost, and the small amounts of the metal used in photography and for colouring porcelain are used up and not recovered. There is thus little loss of material, and one often wonders what becomes of the large amounts of gold produced year after year.

The *total production of gold* in the year 1883 was estimated to be of the value of twenty million pounds sterling, while the value of that produced in 1899 was sixty million, this large increase being a result of the discovery of the rich deposits of the Transvaal. There is a striking difference between such amounts and the production of former times. Thus, during the three and a half centuries which elapsed between the

discovery of America and the discovery of the Californian gold-fields, 1493—1850, it is estimated that the gold produced amounted to 4,750,000 kilograms, whereas in the eleven years 1885—1895 the total production was 6,050,000 kilograms. The continued increase during recent years is shown in the following table. There is not the slightest fear of the exhaustion of the world's gold resources, as was at one time suggested by the advocates of a silver standard of currency.

The details of production of the principal gold-producing countries given in the following table are taken with some modifications from "The Mineral Industry". For the year 1898 the percentages of the total amount yielded by the three principal countries are — the Transvaal 27 per cent., the United States 22½ per cent., Australia 21½ per cent., which together amount to 71 per cent. of the total. During 1905 the total production for the world amounted to 580,087 kilograms, and of this amount 342,005 was produced in the British Empire.

Countries	1898		1901		1905	
	Kilograms*)	Value in Dollars*)	Kilograms	Value in Dollars	Kilograms	Value in Dollars
North America:						
United States	*97932·9*	65802430	*120691·0*	80211545	*132519·6*	87948237
Canada	*20613·9*	13700000	*36807·4*	24462222	*21800·0*	14486833
Mexico	*12393·5*	8236720	*15554·2*	10329316	*21860·0*	14526855
Central America	*790·0*	525000	*1549·8*	1030000	*1686·3*	1120700
South America:						
Brazil	*3809·3*	2531687	*4514·0*	3000000	*3651·5*	2426575
Colombia	*5567·3*	3700000	*3114·7*	2070000	*2970·8*	1974400
Chile	*2118·0*	1407623	*677·1*	450000	*958·4*	636900
Guiana (Brit., French and Dutch)	*5739·0*	3814150	*5567·9*	3700441	*6322·7*	4201857
Africa:						
Transvaal	*117470·3*	78070761	*7432·9*	4939944	*152324·1*	101225558
Rhodesia	*652·5*	433682	*4626·4*	3074730	*10840·4*	7203865
Asia:						
British India	*11684·9*	7765807	*14178·2*	9422855	*17943·7*	11924308
China	*9992·8*	6641190	*4514.0*	3000000	*6771·0*	4500000
Japan	*1073·3*	713300	*2300·0*	1528580	*6771·6*	4500000
Korea	*1646·1*	1094000	*3460·7*	2300000	*1805·7*	1200000
Australia	*93732·3*	62294481	*115947·8*	77058938	*129369·2*	85970779
Europe:						
Russia (including Siberia)	*37217·0*	24734418	*38988·5*	25911744	*33402·3*	22197155
Hungary	*3068·0*	2038993	*3270·1*	2173308	*3668·7*	2438006
Germany	*2847·0*	1892116	*112·0*	74435	*3933·0*	2613639
United Kingdom	*9.0*	6321	*161·2*	107267	*422·5*	280781

*) To convert Dollars to £ divide by 5; to convert kilograms to ounces multiply by 31 ½.

Platinum.

This metal was discovered in the Choco district in Colombia, South America, and was first brought to Europe in the year 1735. It was called platina in Spanish, since it is a white metal somewhat resembling silver (Spanish, plata). Although the native metal has since been found at some other localities and has been much sought for, it is still one of the rarest of metals. It occurs also in very small quantities in some gold ores. Only one compound of the metal is found in nature; this is the mineral *sperrylite*, a compound of platinum with arsenic, with the formula $PtAs_2$, which occurs as small cubic crystals with a tin-white colour and metallic lustre in the province of Ontario in Canada.

Native platinum is found almost exclusively in alluvial deposits in the form of small isolated scales and grains, less frequenty in large grains and nuggets. The largest piece on record was found in the Ural Mountains, and it weighed 10 kilograms. The grains have a smooth or a rough surface, and are often pitted. Crystals, which have the form of a regular cube, are extremely rare. Two pieces of native platinum are represented in plate 5; that in fig. 15 weighs 54·3 grams, and the other, fig. 16, 621 grams. Nuggets of the size here shown are of rare occurrence. Professor G. Rose counted only five which each weighed over 500 grams in a collection of 3384 platinum nuggets all of them over $4^1/_2$ grams in weight.

The colour of native platinum is steel-grey, while that of the pure metal is silver-white. It is malleable and ductile, and its hardness exceeds that of gold and silver. The specific gravity of the native metal varies between 14 and 19, that of pure platinum being 21·5; it is therefore the heaviest of metals, with the exception of iridium and osmium. The considerable variation in the specific gravity of native platinum is due to the presence of impurities, namely, 5—16 per cent. of iron, some iridium, rhodium, palladium, osmium and copper. The fact that some grains of native platinum are strongly magnetic with polarity is probably due to the presence of iron.

Platinum is very resistant to acids, being dissolved only by aqua regia. It is also very difficultly fusible, the melting point being about 1770° C. For these reasons the metal finds many applications in the chemical laboratory and in chemical industries, and its place could be taken by no other metal. It is easily attacked when heated with sulphur, arsenic, or easily fusible metals; these substances should therefore not be heated in a platinum crucible or on platinum wire.

The greater part of the platinum now found is of Russian origin, coming from a district about 5000 square kilometres in area on the upper Tura river, which is situated on the eastern side of the Urals in government Perm. The richest deposits are on the Iss, a tributary of the Tura, and were discovered in 1825. In the district of Nizhne-Tagilsk, some hundreds of kilometers to the south, large quantities have also been won; and the large nugget represented in plate 5, fig. 16, is from this locality. The mother-rock of platinum in the Urals is a serpentine, which has been formed by the weathering of an olivine-rock: the latter is an igneous rock, which was intruded as a molten magma, bringing with it the precious metal.

Platinum is also found in Colombia in South America (where it was first discovered), in Brazil, California and British Columbia, being associated in these countries with gold; in Borneo, where it is associated and intergrown with iridosmine; and in New South Wales and New Zealand.

Platinum has several important uses. In the chemical laboratory it is used in the form of wire and foil, and as a material for crucibles, dishes, retorts, etc. The chemical manufacturer uses platinum vessels for the concentration of sulphuric acid. The points of lightning conductors are made of platinum. Formerly the metal was used for coins in Russia, but owing to its rarity this is no longer the case. The nominal value of the three rouble piece (fig. 109) when coined was 9s. 7d., but at the present price of platinum it is worth double this amount: the coin weighs 10·3 grams. Altogether 14,250 kilograms of platinum were coined, and since then the value of this quantity has increased by £700,000. The ordinary commercial platinum always contains small amounts of iridium, about 0·1 to 1·5 per cent. Chemically pure platinum is almost as soft as pure gold, and like the latter it must be alloyed with some other metal to make it more resistant to wear. For many purposes alloys rich in iridium are more suitable than is ordinary platinum.

Fig. 109.
Russian platinum coin.
3 rouble piece.

In addition to its use in the metallic state, salts of platinum also find useful application as chemical reagents and in photography. When ammonium platinum chloride is heated to redness, the platinum remains in a very finely divided state, and this "platinum-sponge" possesses some very remarkable properties: it condenses gases in its pores, and when brought into contact with hydrogen or coal-gas causes them to ignite. Use was made of this property of platinum in the Döbereiner lighter, which is now superseded by self-lighting arrangements attached to gas-burners.

Iridium is a heavy metal which occurs in nature alloyed with platinum or with osmium. Most native platinum contains it in small amount, but specimens in which iridium predominates are very rare. When alloyed with osmium it forms the mineral known as *iridosmine* or osmiridium, which is found as thin scales in alluvial deposits in Choco (Colombia), the Urals, and in California. Iridium is fusible only with great difficulty, the melting point being 600° C. higher than that of platinum, so that formerly this metal could not be worked. Now, however, it can be worked up into foil and wire. It is a very hard metal, and has a specific gravity of 22. Iridium finds an important application in the construction of the Chatelier pyrometer, which is a form of thermometer capable of measuring temperatures up to 1600° C. Wires of platinum and iridium are soldered together to form a thermo-electric couple: when the junction is heated an electric current is generated, the strength of which is dependent on the temperature and may be measured by means of a galvanometer. Still higher temperatures — 1600° to about 2200° C. — may be measured in this way by constructing the thermo-electric couple of pure iridium and of an alloy of iridium and ruthenium.

Osmium is another heavy metal which is won in small amounts as a by-product from platinum, the amount being about 32 kilograms from 5000 kilograms of platinum. This has been used for the mantles of incandescent gas-lights and for the filaments of electric lamps. Osmic acid, a compound of osmium and oxygen, is used in the preparation of microscopic sections of animal tissues. Chemically pure osmium has a specific gravity of 22·5, and is the heaviest known substance.

In the production of platinum Russia takes the first place, contributing over 90 per cent. of the total amount. In the year 1900 Russia produced 5100 kilograms (165,000 ounces troy), and in 1905, 5241·3 kilograms. Colombia in South America yields annually about 356 kilograms (11,500 ounces). In the United states about 6 kilograms per annum are separated from the gold coined at the mint in San Francisco. Appreciable amounts of platinum are known to occur in New South Wales, but, owing to want of

water, there are practical difficulties in winning the metal. The demand for platinum is greater than the supply, and hence the price has continually been increasing, though subject to great fluctuations, and at the present time exceeding that of gold. In 1903 the price of a kilogram of commercially pure platinum was £125, and in 1907 about £140.

Native Silver and Silver Ores.

Native Silver.

Native silver, like native gold, has been known from the earliest times. It is not, however, so readily won as is gold, for it never occurs as rolled fragments in the beds of streams, but is always found in the solid rock, though usually quite near to the earth's surface. Silver resembles gold in the ease with which it can be wrought, in its mode of occurrence, and in many of its characters. It has not, however, the unalterable lustre of gold, and in contact with the air it soon becomes tarnished and black: it is less permament than gold and differs from it also in colour. For these reasons, and also because of its greater abundance, silver is less valuable than gold. Moreover, silver more readily forms compounds with other elements than does gold; several minerals containing silver as an essential constituent occur in nature, and indeed most of the silver which we use has been obtained from the metallic ores of this metal.

Native silver, when in a fresh and unaltered condition, is white with a metallic lustre; usually, however, owing to the formation of a film of sulphide of silver, it is dulled on the surface by a yellowish or blackish tarnish. It crystallizes in the cubic system, and is found as well-formed crystals, or more frequently as delicately branching forms, or as platy, wiry, dentiform, or mossy aggregates, which frequently present a certain resemblance to the forms of plants.

Some examples of well-formed crystals of native silver from Kongsberg in Norway are illustrated in plate 6, figs. 1—3: they are attached to calcite, with which is a little fluor-spar and quartz. In fig. 1 the form is the cube, and in fig. 2 the octahedron; while the unusually large crystal shown in fig. 3 (on a large piece of massive native silver) is a combination of the cube and the octahedron. The small crystals shown in fig. 4 are also bounded by faces of the cube and the octahedron. Very frequently the crystals are twinned on a face of the octahedron: the crystals represented in figs. 1, 2 and 4 are so twinned, though this is not evident in the figures. A twinned crystal is shown in the upper part of fig. 5; the triangular face is that of the octahedron, and the three faces bordering on it belong to the icositetrahedron $3\,O\,3$; the other side of the same crystal is also bounded by one octahedral face and three faces of the icositetrahedron; the whole form being thus bounded by only two faces of the octahedron and six of the icositetrahedron, with the omission of the remaining six octahedral faces and eighteen icositetrahedral faces. This peculiar development of the crystal is due to twinning on the octahedral face.

The plate of native silver represented in plate 6, fig. 6, and again in plate 7, figs. 2 *a*—*c*, consists of an aggregation of such twinned crystals arranged in rows parallel to the three sets of lines at 60° which bisect an octahedral face. The thicker crystals at the end of the branches show very distinctly the form of the icositetrahedron (plate 7, fig. 2 *c*). At several places (especially in fig. 2 *a*) the triangular outline of the individual

crystals is clearly visible: while in other parts (fig. 2*b*) these triangular faces are greatly elongated in one direction, giving rise to the network of branches intersecting at angles of 60°. This plate of silver with its delicate and beautiful regularity of crystalline structure has been described in detail from a purely crystallographical point of view by the late Professor G. vom Rath.

Another plate of native silver is represented in plate 7. fig. 3, and this exhibits a striking resemblance in its structure to the plate of gold (figs. 1*a*, 1*b*) already mentioned. The small triangular markings on its surface are in reversed positions with respect to one another in the upper and the lower parts of the figure; this reversal in position being due, as in the plate of gold, to twinning.

In the specimen of dendritic silver shown in plate 6, fig. 7, from the Sophie mine, at Wittichen in the Black Forest, the branches are at right angles to the main stem, and springing from these branches are still smaller branches again at right angles. This particular dendritic growth, which has a certain resemblance to a fir-tree, is due to the aggregation of numerous minute octahedra along the three rectangular cubic axes. Other tree-like or fern-like aggregates of silver crystals are represented in figs. 8 and 9; here the branches are at angles of 60°.

Fig. 4 of plate 7 shows a wiry form of native silver on calcite, and fig. 10 of plate 6 another wiry form twisted like a cork-screw. Fig. 11 of plate 6 shows a mossy form of native silver, due to the matted aggregation of numerous small wires. Such twisted wiry forms are especially characteristic of native silver. Sometimes these wires are rather thicker and curved like an elephant's tusk, so that they may be described as dentiform (fig. 12); or again they may be flattened, then resembling in form curved chips or shavings of wood (fig. 13); or they may be twisted in and out giving rise to a variety of shapes (fig. 14). It is usually possible to detect on the thicker portions of the wires some traces of crystal-forms, showing that the wires themselves are really distorted crystals. These wiry forms of native silver have usually grown out from a mass of silver sulphide (a grain of which may be seen in fig. 12), which has been acted upon by a reducing solution, whereby the sulphur is removed and the silver left free.

Silver is malleable and ductile to a high degree, and its hardness is not great, being rather less than that of calcite. The specific gravity of the native metal varies from 10 to 11; it does not range between such wide limits as does the specific gravity of native gold. The reason for this lesser variation is that native silver consists mostly of pure silver with usually only traces of gold or copper. Some specimens from Kongsberg in Norway contain, however, as much as 27 per cent. or even 50 per cent. of gold, but these auriferous silvers are quite exceptional, and they form a passage to amalgam. When the silver is dissolved in sulphuric acid the gold remains behind, and this is a means employed to separate the two metals. From the old German thalers much gold was obtained in this way. Pure silver fuses at a temperature of 945° C.

Native silver is usually found in veins in crystalline schists, granite and sedimentary rocks, and it is often associated with calcite, fluor-spar, barytes, quartz, and the sulphide silver ores which will be dealt with further on. These silver ores increase in amount in the deeper parts of the vein, whilst in the upper part of the vein their place is taken by native silver or sometimes by native silver and chloride of silver. It is thus clear that the native silver has been derived from the sulphide silver ores by their weathering in the upper parts of mineral lodes.

Well-known localities for native silver in Germany are the following. At Freiberg in Saxony, especially in the Himmelsfürst mine, where a mass weighing 4—5 hundredweights was found; the specimens shown in plate 6, figs. 8 and 13, are from

here. At Schneeberg and Johanngeorgenstadt, also in Saxony: in the fifteenth century it is said that a mass of silver and silver sulphide weighing 400 hundredweights was found at Schneeberg. At Wittichen in Baden (fig. 7). and at Andreasberg in the Harz Mountains.

In the Bohemian Erzgebirge, silver is won at Joachimsthal, and it is said that the name of the German thaler is derived from the fact that these coins were made of Joachimsthal silver. The silver mines at Kongsberg in Norway have long been famous for the large amounts of native silver which they have yielded, and for the exceptionally fine specimens of this mineral which have been there found: the best specimens represented in plates 6 (figs. 1—6, 9, 12, and 14) and 7 (figs. 2, 3 and 4) are all from this locality. These richer deposits have now been worked out, and at the present time the mines only yield an ore poor in silver, their annual production amounting to about 5000 kilograms of silver. Native silver has been found in many of the Cornish mines, though usually only in small amounts, and in the form of very fine twisted wires.

Larger quantities of native silver are found in North and South America than in Europe. Mexico is especially rich, and so are Chile and Peru. Two specimens of native silver from the neighbourhood of Guanajuato in Mexico are shown in plate 6, figs. 10 and 11. It is also found at several places in the United States: and of especial interest is the occurrence of native silver in close association with native copper in the amygdaloidal melaphyre rocks of the Lake Superior district in Michigan.

On the whole, native silver is much less widely distributed than is native gold, and most of the silver which we obtain is won from the ores of silver, which contain this element in chemical combination with sulphur, antimony and arsenic. At all the localities mentioned (except Lake Superior) these sulphide compounds of silver occur with the native silver, and from them the bulk of the metal is obtained. Since the native silver occurs in the upper parts of the mineral-veins, it is naturally the first to be found, while the richer silver ores are won when the mining is carried on deeper.

The applications of silver and the amount of its production will be mentioned after we have described the more important silver minerals.

Silver Ores.

The ores of silver consist of one or more elements in chemical combination with silver; these elements may be sulphur, antimony or arsenic, and less frequently chlorine, bromine or iodine. The more important silver minerals which we shall describe here are argentite, dyscrasite, the red silvers, stephanite and horn-silver; the rare mineral argyrodite will also be briefly described, being of interest as the source of the recently-discovered element germanium. Among other silver minerals one of the more important is polybasite, which somewhat resembles stephanite in appearance and consists of the same elements, but combined in different proportions. Silver also is often present in galena in small amounts, and in tetrahedrite sometimes in large amounts; these two minerals, which are frequently of importance as silver ores, will be considered with the lead and copper ores respectively.

Argentite, or silver-glance, contains a larger proportion of silver than any other ore and is therefore of first importance. It consists of 87·1 per cent. of silver and 12·9 per cent. of sulphur, this composition being expressed by the formula Ag_2S. Other elements are only exceptionally present, and the mineral is usually pure silver sulphide;

for instance, the analysis of a crystal, from Freiberg in Saxony, showed the presence of 87·09 per cent. of silver. These constituents can be readily detected by heating a fragment of the mineral before the blowpipe together with sodium carbonate on charcoal, when a bright bead of metallic silver is obtained. The fused yellowish mass on the charcoal if placed on a silver coin and moistened with water produces a black stain, thus proving the presence of sulphur.

The colour of argentite is dark lead-grey to black, and the lustre is metallic. A bright metallic lustre is, however, only to be seen on specimens which have not been exposed to the light for any length of time, or on a freshly cut surface of the mineral: on exposure to light the surface soon becomes dull and acquires a sooty coating. Argentite is highly sectile and malleable, and can be cut and hammered out like metallic lead. Masses of larger size, such as are found at Freiberg in Saxony, are sometimes carved by the miners; and King August of Poland caused some medals bearing his portrait to be struck in argentite. The hardness of the mineral is low, being a little over 2 on the scale; and the specific gravity is 7·35.

On account of its softness and malleability, the mineral is called "soft ore" by the Hungarian miners. The old German name "glass-ore" (Glaserz), used as far back as 1546 by Agricola for this and some other similar minerals, is singularly inappropriate, for the mineral possesses neither the transparency nor the brittleness of glass. Another old name, glance-ore (German, Glanzerz), is more in agreement with the characters of the mineral, but it could be equally well applied to several other minerals. The name argentite, given by W. von Haidinger in 1845, is from the Latin argentum, silver.

Argentite crystallizes in the cubic system, the most frequent form being the cube combined with the octahedron (plate 8, figs. 3, 4, 6), or the octahedron with the cube (fig. 5); less frequently, the octahedron occurs as a simple form (fig. 7) or in combination with the icositetrahedron. The crystals are not sharply developed, the faces being curved and drusy (figs. 5 and 7). Peculiar forms of growth, due to the aggregation of crystals, also occur (figs. 8 and 9), but these are not so delicate as in native silver.

Native silver is a common associate of argentite, and the two minerals often pass one into the other. Silver by the addition of sulphur becomes changed to argentite, and argentite when deprived of its sulphur is converted into native silver; wires of native silver may often be seen to have grown from a nucleus of argentite (plate 6, fig. 12). Argentite occurs only in mineral-veins traversing granite or crystalline schists, and is associated with other ores of silver and with quartz.

Amongst the localities where argentite is found, several places in Saxony are noted for producing crystallized specimens; namely, Freiberg (plate 8, figs. 3, 6, 8, 9), Annaberg (fig. 7), Schneeberg, and Johanngeorgenstadt; in the silver mines at these places lumps of pure argentite weighing several kilograms have been found. Other well-known German localities are Andreasberg in the Harz, and Wolfach in the Black Forest. At Kongsberg in Norway large masses were formerly found in association with native silver. The mineral has been found in several Cornish mines, but only in small quantities. Large quantities of massive argentite have been taken from the Comstock lode in Nevada, a locality which has already been mentioned under gold. The silver mines at Zacatecas and Guanajuato in Mexico are also rich in argentite, and specially fine crystallized specimens have been yielded by the silver mines at Chañarcillo in Chile (fig. 5).

Dyscrasite, or antimonial silver, when in a fresh condition is silver-white with a brilliant metallic lustre, but on exposure to light and air it soon becomes grey or yellowish and dull. It is found as small masses or grains embedded in native arsenic (plate 8, fig. 12), or as crystals embedded in limestone (fig. 13). The crystals are orthorhombic,

but are rarely distinctly developed and their faces are deeply and roughly striated (figs. 10 *a* and *b*). In these figures the striated faces shown are those of the base, and the striations are parallel to the macro-pinacoid. The angle between the prism faces differs from 120° by only one minute, so that the four prism faces and the two faces of the macro-pinacoid apparently form a hexagonal prism: in a truly hexagonal crystal, however, the base would be striated in three diagonal directions. The crystals simulate hexagonal symmetry still more closely by being twinned on the faces of the prism, as in aragonite, giving rise to stellate groups. The crystals represented in figs. 10 *a* and *b* each consist of two individuals twinned together on a prism face, as may be seen by the two sets of striations at 60° on the basal planes.

Dyscrasite is composed of silver and antimony, being an antimonide of silver, but the relative proportion of the two elements is somewhat variable, the silver percentage varying from 72 to 84, corresponding with the formulae Ag_3Sb and Ag_6Sb respectively. With this variation in composition there is a corresponding variation in the specific gravity, from 9·4 to 9·9. The hardness is about the same as that of calcite, namely 3.

As an ore of silver dyscrasite is of little importance, and it has been found at only a few localities. Blocks weighing as much as a hundredweight have, however, been raised at Wolfach in the Black Forest, where the mineral occurs with red silver, galena, calcite and barytes (plate 8, fig. 12). It is also not uncommon in the silver veins of Andreasberg in the Harz (figs. 11 and 13).

Cerargyrite, or horn-silver, owes its name to the fact that the mineral can be cut like horn, and the parings resemble horn both in colour and lustre. It consists of silver in combination with chlorine, bromine and iodine, but usually chlorine predominates, and bromine and iodine may be present only in small amount or completely absent. The pure chloride of silver has been called chlorargyrite, and the pure bromide bromargyrite, while minerals containing both chlorine and bromine are referred to as embolite. The different members of the group are not readily distinguished except by chemical analysis. They are not conspicuous minerals, usually occurring as an encrustation on other minerals (plate 8, fig. 14). Crystals have the form of the cubo-octahedron, but are always small and indistinct. The mineral is translucent, its colour is greyish, yellowish or greenish, and its lustre resinous or horny. On exposure to light the material quickly darkens and becomes dull. The mineral is very sectile and malleable, like argentite. Its hardness is low, H. $= 2\frac{1}{2}$, and the specific gravity of the pure chloride is 5·56.

Cerargyrite occurs in the upper oxidized portions of silver-bearing mineral-veins, and it has without doubt resulted by the action of salt solutions (e. g. sea water) on the sulphide ores of silver. It is found in small amounts at Freiberg and Johanngeorgenstadt in Saxony, and in Cornwall. At several places in Chile and at Broken Hill in New South Wales it occurs in large quantities and is there an important ore of silver. At Broken Hill, the locality of the specimen represented in plate 8, fig. 14, the mineral contains both chlorine and bromine and usually also iodine; but the upper portion of the lode which yielded the secondary minerals has now been completely removed by mining, so that cerargyrite is no longer found here.

The *red silvers*, or ruby-silvers, comprise two minerals, which are distinguished as dark red silver-ore and light red silver-ore. Both contain silver and sulphur with the addition of antimony in the darker and of arsenic in the lighter mineral: hence the former is also known as antimonial silver-blende, and the latter as arsenical silver-blende. Other, more usually adopted names, for the two minerals are pyrargyrite and proustite, respectively.

Pyrargyrite, or dark red silver-ore, contains 59·8 per cent. of silver, 22·5 per cent. of sulphur, and 17·7 per cent. of antimony; its chemical formula is Ag_3SbS_3. The presence of each of the constituents can be readily proved by simply heating the mineral with sodium carbonate on charcoal before the blowpipe: a white sublimate of antimony oxide is formed on the charcoal, a bead of silver remains, and the fused mass when moistened with water gives a black stain on a silver coin.

Crystals of pyrargyrite are represented in plate 9, figs. 1—9. The smaller crystals, or the thinner edges and portions of larger crystals, are transparent with a deep ruby-red colour. Thicker crystals, such as that shown in fig. 4, only transmit a red colour when they are held up to a strong light; otherwise they appear opaque with a lead-grey colour and metallic lustre. Sometimes the surface of the crystals is dull grey and without lustre. In all cases, however, the colour of the streak, or the powder of the mineral, is purplish-red. The red colour of the mineral may often be seen on fractured surfaces, as in fig. 5. The strong metallic to adamantine lustre of the crystals is connected, as in diamond, with the high refractive power, the ordinary index of refraction being 3·08 in pyrargyrite.

The crystals belong to the rhombohedral division of the hexagonal system. Sometimes they are bounded by only the base and the hexagonal prism (plate 9, figs. 1 and 2), or more frequently a scalenohedron is the predominating form (figs. 3, 4 and 5). An exceptionally fine crystal is represented in fig. 4; it is bounded on all sides by faces of a scalenohedron, which are striated parallel to the median edges, this striation being due to oscillatory combination with the prism of the second order. The scalenohedral crystal shown in fig. 3 is terminated by the basal plane; and the small scalenohedron on the upper part of fig. 5 is remarkable for the sharpness of its edges. The latter quite resembles a crystal of calcite in its form, especially as the angles between the faces differ by only about one degree in the two minerals. In other crystals, especially those from Andreasberg in the Harz Mountains, the prism of the second order is combined with a very obtuse scalenohedron $\frac{1}{4}R3$ (fig. 8), or less frequently with an obtuse hexagonal pyramid $\frac{2}{3}P2$ (fig. 7). On this pyramid the angles over the six edges meeting at the top of the crystal are all equal, being 153° 5′; but on the obtuse scalenohedron there are two sets of edges meeting at the top of the crystal, the angles between the faces over three of the edges being $160\frac{1}{2}^0$ and over the three alternate edges $140\frac{1}{2}^0$.

The specimen shown in plate 9, fig. 9, from Andreasberg in the Harz, is remarkable for the size and the form of its crystals. The two large faces on the crystal to the right belong to the scalenohedron $R3$; above are faces of an obtuse scalenohedron $\frac{1}{4}R3$ and an obtuse rhombohedron $-\frac{1}{2}R$; and below are faces of the hexagonal prism $\infty P2$. The directions of the striations on the prism faces sometimes indicate that crystals of pyrargyrite are hemimorphic, as in tourmaline, but only rarely are the crystals differently developed at the two ends.

The hardness of pyrargyrite is $2—2\frac{1}{2}$, and its specific gravity is 5·85. The crystals possess three directions of distinct cleavage parallel to the faces of the primary rhombohedron, and the angles between them differ by only a few degrees from those between the more perfect cleavages of calcite. There is thus a certain amount of crystallographic similarity between these two minerals.

Pyrargyrite is found as crystals and as compact masses in association with other silver ores and with calcite in mineral-veins. Well-known occurrences are those of Andreasberg in the Harz (plate 9, figs. 3, 4, 7, 8, 9), of Freiberg and Annaberg (fig. 1) in Saxony, and Joachimsthal in Bohemia. Small, well-developed crystals are found with galena in the Gonderbach mine at Laasphe in Prussia (fig. 6) and at Wolfach

in the Black Forest. Other localities are Monte Narba in Sardinia, Guanajuato in Mexico (fig. 2), Chañarcillo in Chile (fig. 5), and Colquechaca in Bolivia.

When found in quantity, pyrargyrite is an important ore of silver. It sometimes has been altered to argentite or to native silver.

Proustite, or light red silver-ore, contains 65·6 per cent. of silver, 19·4 per cent. of sulphur, and 15 per cent. of arsenic, its chemical formula being Ag_3AsS_3. When heated before the blowpipe it behaves like pyrargyrite, but gives the reaction for arsenic instead of antimony, the former being recognized by the garlic-like odour of the fumes which are emitted.

Proustite is much more transparent than pyrargyrite, and even the thickest crystals allow the passage of a magnificent ruby-red colour; the metallic to adamantine lustre is also more brilliant. On exposure to light the crystals soon become black and opaque with a dull surface. The colour of the streak is scarlet, and this affords an easy means of distinguishing proustite from pyrargyrite, which gives a much darker coloured streak. The crystals have the same degree of symmetry as in pyrargyrite, and sometimes they show indications of a hemimorphic development. Thus, in the fine crystal represented in plate 9, fig. 10, the hemimorphism is shown by the triangular form of the prism; the faces of this triangular prism are deeply striated vertically owing to oscillatory combination with other prism faces; and the dull end faces are those of an obtuse scalenohedron. The more acute scalenohedron $R\,3$ (figs. 11 and 12) is a commoner form of proustite crystals. The hardness of the mineral is $2\frac{1}{2}$, and its specific gravity 5·57.

Light red silver-ore is of rarer occurrence than the dark red silver ore. It is found in the mineral-veins of Joachimsthal in Bohemia (fig. 10); in the Himmelsfürst mine at Freiberg, at Annaberg and Marienberg, in Saxony; at Wittichen in the Black Forest, and at Markirch in the Vosges. Magnificent crystallized specimens consisting of groups of large scalenohedra are well-known from the silver mines around Chañarcillo in Chile, from which locality come the specimens represented in figs. 11 and 12. On account of the ruby-red colour and brilliant lustre of the transparent crystals such specimens are eagerly sought for by collectors, adding interest and beauty to any collection of minerals; whilst massive material is of value as an ore of silver.

The sulph-antimonite of silver with the formula Ag_3SbS_3, which we have already met with as pyrargyrite, also occurs in nature crystallized in the form of thin monoclinic plates which are transparent with a hyacinth-red colour. This represents another mineral species, dimorphous with pyrargyrite, and known as *pyrostilpnite* or fire-blende. In the same way the sulph-arsenite of silver, Ag_3AsS_3, also is dimorphous, occurring as the rhombohedral mineral proustite and also in orange-yellow to dull red monoclinic scales, the latter mineral being known as *xanthoconite*. Both of these monoclinic species of red silvers are of very rare occurrence, and are only of scientific interest; the first is found in the silver veins of Andreasberg, and the second at Joachimsthal in Bohemia and Chañarcillo in Chile.

Stephanite is also known as "black silver-ore" and as "brittle silver-ore" on account of its black colour and its brittleness. The crystals have a bright metallic lustre, but on exposure to light they soon become dull with a sooty surface. The streak is iron-black. The mineral (plate 9, figs. 13—15) crystallizes in the orthorhombic system, but in forms which show a resemblance to hexagonal crystals. The rhombic prism has an angle of 115° 40′ between its faces, and in combination with the brachy-pinacoid the form resembles a hexagonal prism; in fig. 14 such a combination is terminated by the basal plane. A rhombic pyramid in combination with a brachy-dome produces an apparent hexagonal pyramid, as in fig. 15 *a*, where the pyramid is truncated by the large

basal plane shown to the front. Less frequently the crystals have a long-prismatic habit, as in fig. 13. Twinning on the faces of the prism is frequent, giving rise to stellate groupings (figs. 15 *b* and 16) or pseudo-hexagonal crystals.

Besides occurring as crystals, stephanite is often found as compact masses, when it may be easily confused with other minerals. It may, however, be recognized by its blowpipe reactions, which are the same as those given by pyrargyrite. Stephanite and pyrargyrite are composed of the same chemical elements, but these are combined is different proportions in the two minerals. The formula of stephanite is Ag_5SbS_4, corresponding with the following percentage composition: silver 68·50, antimony 15·22, and sulphur 16·28. This mineral is thus one of the richest of silver ores. Although it shows a certain resemblance in crystalline form to pyrargyrite and gives the same blowpipe reactions, it may be distinguished from this by its black colour and streak. The hardness is $2—2\frac{1}{2}$, and the specific gravity 6·2.

Stephanite is found together with other silver minerals in the veins of Andreasberg in the Harz (figs. 14—16), Freiberg in Saxony, Przibram (fig. 13) and Joachimsthal in Bohemia, and Schemnitz in Hungary. Large quantities of the massive mineral have been raised from the Comstock lode in Nevada (p. 81).

Argyrodite is a mineral of great rarity, and is mentioned in this place as being of special interest in connection with the comparatively recent discovery of the metallic element germanium. The mineral was found in 1886 as botryoidal masses with a minutely crystallized surface (plate 9, fig. 17), in the Himmelsfürst mine at Freiberg, Saxony, and when analysing it Professor Clemens Winkler detected the new element. The colour is black with a violet tinge, and the lustre metallic. Well-developed cubic crystals have been more recently found in Bolivia.

Winning of silver. — Silver is extracted from the minerals mentioned above and also from some others, especially galena, since this often contains the metal in small amounts. A method often adopted is first to obtain the silver in alloy with lead, which may be done by smelting the silver ore with roasted galena, or by adding the ore to molten lead. The litharge, or yellow oxide of lead, formed by the oxidation of the galena, acts on the silver ore, setting free the silver, and this is taken up into solution by the molten lead, while the other constituents of the ore remain on the surface. The silver is then extracted from the alloy of silver and lead so obtained by the process of cupellation, whereby the lead is converted into oxide and the silver left behind as metal. Or, according to a method introduced by Parkes, the silver-rich alloy is fused with zinc, which takes up the silver, together with any gold that may be present; the alloy of zinc and silver is then heated to distil off the zinc, and the last traces of lead are removed from the metallic silver by oxidation.

Uses of silver. — The applications of silver are much the same as those of gold, the larger part of it being used for coinage. The British imperial silver coinage has a fineness of 925, consisting of 925 parts of silver alloyed with 75 parts of copper, or in the ratio of 37 to 3: this is known as standard silver. The silver coins of Germany and the United States, with a fineness of 900, contain rather less silver. During the last few decades the value of silver, compared with that of gold, has depreciated considerably. By the French edict of October 30, 1785 the value of gold was fixed at fifteen-and-a-half (15·5) times that of an equal weight of silver. This "universal" ratio of value had, previous to the edict, held good for two centuries, and it was accepted by the Latin coinage union on December 23, 1865. According to this ratio the value of an ounce of silver on the London market was $60\frac{13}{16}$ pence. This "universal" ratio was for a time subject to only slight variations. The large quantities of gold produced by

California had the effect of increasing the price of silver; but the introduction of a gold coinage into Germany in 1873 and the increased production of silver in America had the opposite effect, so that in the nineties the price of silver had fallen to half its former amount. Thus, to purchase a kilogram of gold required in 1865 only 15·5 kilograms of silver, but in 1895 31·6 kilograms of silver had to be given, and in 1902 as much as 38·6. This rapid decrease in the value of silver is well shown in the following table, in which is given the ratio of the value of silver to that of gold and the corresponding price in pence of an ounce of silver.

Year	Ratio of value of silver to gold	Price of one ounce of silver in pence	Year	Ratio of value of silver to gold	Price of one ounce of silver in pence	Year	Ratio of value of silver to gold	Price of one ounce of silver in pence
1870	1:15·55	$60^{9}/_{16}$	1883	1:18·58	$50^{9}/_{16}$	1896	1:30·64	$30^{3}/_{4}$
1871	1:15·56	$60^{1}/_{2}$	1884	1:18·59	$50^{5}/_{8}$	1897	1:34·30	$27^{9}/_{16}$
1872	1:15·57	$60^{5}/_{16}$	1885	1:19·31	$48^{5}/_{8}$	1898	1:34·97	$26^{15}/_{16}$
1873	1:15·80	$59^{1}/_{4}$	1886	1:20·69	$45^{3}/_{8}$	1899	1:34·28	$27^{7}/_{16}$
1874	1:16·01	$58^{5}/_{16}$	1887	1:21·05	$44^{5}/_{8}$	1900	1:33·31	$28^{1}/_{4}$
1875	1:16·52	$56^{7}/_{8}$	1888	1:21·92	$42^{7}/_{8}$	1901	1:34·62	$27^{1}/_{5}$
1876	1:17·69	$52^{3}/_{4}$	1889	1:22·06	$42^{11}/_{16}$	1902	1:38·62	$24^{5}/_{16}$
1877	1:17·20	$54^{13}/_{16}$	1890	1:19·74	$47^{11}/_{16}$	1903	1:38·59	$24^{3}/_{8}$
1878	1:17·86	$52^{9}/_{16}$	1891	1:20·91	$45^{1}/_{16}$	1904	1:35·66	$26^{3}/_{8}$
1879	1:18·34	$51^{1}/_{4}$	1892	1:23·64	$39^{13}/_{16}$	1905	1:33·76	$27^{13}/_{16}$
1880	1:18·03	$52^{1}/_{4}$	1893	1:26·58	$35^{5}/_{8}$	1906	1:30·41	$30^{7}/_{8}$
1881	1:18·16	$51^{11}/_{16}$	1894	1:32·52	$28^{15}/_{16}$			
1882	1:18·14	$51^{5}/_{8}$	1895	1:31·59	$29^{7}/_{8}$			

All attempts which have been made to preserve a constant ratio of value between the two metals have been without success. Any international agreement to increase the price of silver would immediatly result in an increased production of the metal and its price would consequently fall. Nevertheless silver remains an important metal for coinage and it can be replaced by no other.

Besides its use for coinage, silver has from the earliest times been used in large amounts for ornaments and utensils of various kinds. Bottles, cups and basins of worked silver have been found amongst the ancient remains of the second settlement of Troy; whilst at the present day silver is the metal preferred for spoons, forks, candle-sticks, basins, cups, table ornaments, and for delicate filigree work. In the chemical laboratory, dishes and crucibles of pure silver are made use of; and in chemical works, silver worms are used for cooling or heating liquids. Compounds of silver also find an extensive application: the nitrate is used in medicine for cauterization, and in the laboratory as a reagent for detecting chlorides. Silver chloride, bromide and iodide are largely used in photography: at the present time with dry plates the bromide is most commonly used, whilst with the earlier daguerrotype and collodium methods the iodide of silver was used.

Production of Silver. — From the following table, giving the production of silver during recent years of different countries, it will be seen that the United States and Mexico produce the largest amounts. Australia takes a third place, but the yield is here much less than that of either the United States or Mexico. A fourth or fifth

place in the list of silver-producing countries is occupied by Germany, but here a large proportion (in 1898 more than one-half) is extracted from imported ores: of ores actually mined in Germany the Kupferschiefer (copper-shale) of Mansfeld yields the largest amount of silver.

Countries	1898		1901		1905	
	Kilograms	Value in Dollars	Kilograms	Value in Dollars	Kilograms	Value in Dollars
North America:						
United States	*1827723*	34670245	*1855425*	35165902	*1832623*	35850955
Canada	*137913*	2616110	*157952*	2993668	*185844*	3605957
Mexico	*1768501*	33546855	*1715416*	32512304	*2203361*	42750773
South America:						
Bolivia	*342138*	6490000	*290191*	5500000	*205288*	3983100
Chile	*143514*	2722245	*179552*	3403059	*26438*	512975
Colombia	*51200*	971187	*78380*	1485540	*31103*	603500
Peru	*58368*	1107188	*207000*	3923274	*155521*	3017500
Australia	*534360*	10136013	*337420*	6395144	*446738*	8667853
Asia:						
Japan	*78009*	1479759	*58953*	1117337	*100000*	1940153
Europe:						
France	*80351*	1524138	*14067*	266612	*19221*	372948
Spain	*229000*	4343786	*183802*	3483602	*117418*	2278281
Germany	*480578*	9115744	*168349*	3190721	*389898*	7565267
United Kingdom	*7007*	132916	*5194*	98447	*4967*	96376
Total for the world	*5575335*	105364505	*5438443*	102769792	*5904509*	114856349

Native Copper and Copper Ores.

Native Copper.

Native copper, like native gold and silver, was one of the metals earliest known to man. The copper ore (aes Cyprium) from the ancient mines on the island of Cyprus was long ago worked by the Phoenicians, and it is from this island that the name copper is derived through the Latin cuprum. The builders of the pyramids of Gizeh are said to have obtained copper in the Sinai peninsula three thousand years before Christ; and amongst the treasure dating back to the second settlement of Troy articles of pure copper have been found. Many of the objects belonging to these remote

times are made of bronze, an alloy of copper and tin, so that ores of both these metals were sought and worked.

It has been pointed out above that silver combines with other chemical elements much more readily than does gold; we have now to add that copper combines with other elements more readily than does silver. For this reason native copper only rarely exhibits the copper-red colour and bright metallic lustre so characteristic of this metal; more usually the surface is tarnished and dull, but the true colour is at once revealed when the surface is scratched with a knife.

Like gold and silver, copper crystallizes in the cubic system, and moreover it frequently also exhibits dendritic and platy forms of growth. The most frequent forms of crystals are the rhombic-dodecahedron (plate 10, fig. 1), the tetrakis-hexahedron or four-faced cube with the symbol $\infty O \frac{5}{3}$ (fig. 2), and the cube (fig. 3). Large and distinctly developed crystals, like the four-faced cube represented in fig. 2, are of rare occurrence; usually they are much obscured by elongation in one direction (fig. 4), or by twinning on an octahedral face. Most crystals of native copper when closely and critically examined will be found to show evidences of twinning. In the specimen represented in fig. 3 each single crystal is a cube twinned on an octahedral face in such a manner that the crystal has the appearance of a double three-sided pyramid: such a crystal is distinctly to be seen in the centre of the specimen. This mode of twinning is illustrated in the accompanying text-figure 110: we may imagine a cube to be cut into two equal portions by a plane parallel to the octahedral face which would truncate the upper right-hand corner of the cube, and that one half is rotated through 180° about an axis perpendicular to this plane, that is about a diagonal of the cube. If now, the re-entrant portions of the twinned crystal become filled up with material, the resulting form will have the shape of a double triangular pyramid, as may be readily imagined from fig. 110. This type of crystallization of native copper is well shown in plate 7, fig. 5; the triangular pyramids projecting from the surface of the specimen are each of them twinned cubes, which are arranged in parallel positions along three directions at 60°, parallel to the diagonals of an octahedral face. The fact that these crystals are twinned could not be made out from the figure, and indeed with the actual specimen it is not at first obvious, for the crystals on the opposite side are quite small and not very distinct. On other specimens of native copper the crystals are often flattened parallel to one pair of faces of the octahedron, and they may also be elongated in one direction. Such flattened and distorted crystals are frequently grouped together in parallel positions and intercross one another at 60°, giving rise to the delicate branching and tree-like forms represented in plate 10, figs. 5—8, similar to those already described for native gold and silver. When the flattening of the individual crystals is still more pronounced, the aggregate will have the form of a plate with perhaps still some indications of the dendritic form (fig. 10); or in an extreme case we may have simply a thin plate or foil much twisted and curved (fig. 11).

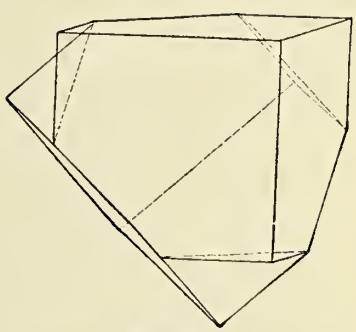

Fig. 110.
Twinned cube of native copper.

The thick plate of native copper represented in plate 10, fig. 12, shows no indications of crystalline structure on its surface: the edges are rounded and the surface marked with concave depressions, two of which completely penetrate the plate. The whole appearance of this specimen suggests that the material has been fused, but this

is excluded by the mode of occurrence, and we must conclude that the rounding of the mass has been produced by corrosion.

Wiry forms, such as are especially characteristic of native silver, are of rare occurrence in native copper. The specimen represented in plate 10, fig. 9, is an example of this; and a close examination of the actual specimen reveals a regularity of crystalline growth. It consists of a six-sided rod with sharp edges and depressed surfaces, the latter being marked by fine feather-like striations; besides being curved, the rod has a helical twist about its long axis, and the short hook-like portion at the upper end is inclined at 60^0 to the main axis. The six faces of the prism are those of an icositetrahedron perpendicular to an octahedral face, which if present would truncate the prism perpendicularly to its length: the hook at the upper end is due to twinning on a second octahedral face. This specimen is said to be from the Lake Superior copper-mining region, but it is possible that it is of artificial origin, for forms exactly like this have come from the copper refining furnaces at Hamburg.

Native copper is usually almost chemically pure copper, containing sometimes only a little silver. Its specific gravity is consequently subject to only slight variations from the mean value of 8·9. Its hardness is the same as that of calcite, H. = 3; and like the other soft metals, it is highly malleable and ductile. The metal is readily attacked by acids, and is soon dissolved by strong acids: it is even soluble in an aqueous solution of ammonia. Pure copper melts at a temperature of 1050^0 C. and in contact with air the surface of the molten metal becomes coated with a film of black oxide. The usual products of weathering in nature are the red oxide (cuprite) and the green carbonate (malachite).

As a mineral, native copper occurs with various ores of copper in mineral-veins, or it occurs on the surfaces of crevices in sandstone, slates and igneous rocks; it is also sometimes found with calcite and zeolites in the amygdaloidal cavities of melaphyres. Some of the more noteworthy occurrences of native copper are mentioned below; some of them are of importance as commercial sources of the metal, and some are of interest from other points of view.

In Germany, native copper is found only very rarely and never in large amounts. It was formerly found with quartz in veins in the grauwacke of the Virneberg at Rheinbreitenbach, near to Honnef on the Rhine: the dendritic specimen figured in plate 10, fig. 8, is from this locality. Thick platy and corroded masses, up to three kilograms in weight, are found in quartz veins at Hohenstein near Reichenstein in Odenwald (fig. 12). Delicately formed dendritic groups of native copper have been found in the lead and silver mine of Friedrichssegen near Ems in Nassau (fig. 7). Small scales of copper occur in the Kupferschiefer (copper-shale) of Mansfeld in Prussian Saxony, and in the upper oxidized zone of the veins of copper-pyrites in the Siegen and Dillenburg mining districts.

In Cornwall, native copper has been found in many of the copper mines, particularly those in the neighbourhood of Redruth. In the Lizard district it occurs embedded in the serpentine rock, sometimes in masses of considerable size, one block weighing three tons. In Scotland, at Barrhead in Renfrewshire, thin plates of copper occur in crevices of the ancient volcanic rocks, where the metal is usually associated with calcite and prehnite.

The Turjinsk mines situated in the Bogoslovsk district, in government Perm, Russia, are famous for the many fine and well-crystallized specimens of native copper which they have yielded. The specimens represented in plate 10, figs. 3 and 5, show the crystals embedded in a matrix of crystalline limestone, which occurs at the locality

in contact with igneous rocks. Other localities for native copper in the Ural Mountains are in the neighbourhood of Nizhne-Tagilsk, Ekaterinburg, and Kargalinsk. In Siberia, it is found at Zmeinogorsk in the Altai Mountains.

The largest amounts of native copper found in any part of the world are those occurring in the Keweenaw peninsula on the south shore of Lake Superior in the state of Michigan. Resting on the ancient sedimentary rocks of Cambrian age in this district are great thicknesses of melaphyre and quartz-porphyry; and it is in these volcanic rocks, or in veins connected with them, that the native copper occurs, together with native silver, calcite, quartz, prehnite, and various zeolites. The best crystals of native copper displayed in mineral collections have come from this district. Masses of enormous size are sometimes found: the largest on record was found in 1857 in the Minnesota mine; it measured 45 feet in length, 22 feet at its greatest width, and more then 8 feet in its thickest part; it contained over 90 per cent. of pure copper and weighed about 420 tons. Copper occurs in this region over an area 200 miles in length, and practically all of it is in the native state. The total production of all the mines during the year 1898 amounted to 62,668 tons of copper. But although the yield is large there are heavy working expenses; for instance, the sinking of one shaft alone to a depth of 1500 metres cost half a million pounds. Native copper also occurs, sometimes in large blocks weighing over a hundred kilograms, at the Copper Queen mine in Arizona; but here it is not an important ore as in the Lake Superior district.

Considerable amounts of native copper occur on the Bolivian tableland in the neighbourhood of the town of Corocoro, to the south of Lake Titicaca. Here the metal is disseminated in a sandstone of Cretaceous age. It occurs in dendritic (plate 10, fig. 10) and platy (fig. 11) forms; and well-shaped six-sided prisms of native copper pseudomorphous after aragonite are not uncommon (plate 74, fig. 10). In this district copper was long ago worked by the Incas; the modern mining operations date from the year 1832, and the average annual production amounts to 2300 tons. In Chile, native copper occurs in veins associated with granitic and other acid eruptive rocks; it is associated with copper ores, free gold, iron-pyrites, quartz and tourmaline. During the year 1898 Chile produced 25,248 tons of copper, but only a small portion of this represented native copper.

In Africa, the richest deposits of native copper are those in Damaraland in the south-west portion of the continent. The dendritic specimen shown in plate 10, fig. 6 is from this region.

Much native copper has been obtained from South Australia, at Burra-Burra, and especially at Wallaroo and Moonta in the Yorke peninsula. The mines at Burra-Burra are now exhausted, but the two other localities yielded in 1897 5100 tons of copper, though not all from native copper. At Broken Hill, in New South Wales, small but well-formed crystals of native copper have been found.

In other copper-producing countries the metal is extracted mostly from the ores. The applications of copper and the amount of its production will be mentioned after we have described the several ores.

Copper Ores.

Since copper readily enters into chemical combination with other elements, the number of minerals which contain copper as an essential constituent is very large. Some of these minerals, when they occur in sufficiently large amounts may be regarded as

ores of copper. Others occur in association with the ores, and have been derived from them by the action of weathering processes; and in certain cases these also may form part of the workable ore. Others, again, may be of quite rare occurrence and not found in association with the ores. Oxygen compounds of silver are unknown in nature, but of copper they are of very frequent occurrence. Copper is not classed with the precious metals (gold, platinum and silver) because of the fact that it oxidizes so readily. Native copper and the metallic ores of copper when subjected to the action of weathering agencies take up oxygen, carbonic acid and water and are converted into a basic hydrated carbonate of copper, which is the common mineral malachite.

The ores and more important naturally-occurring compounds of copper which we shall here describe are tabulated below with their chemical formulae:

Copper-glance, Cu_2S.	Cuprite, Cu_2O.
Covellite, CuS.	Tenorite, CuO.
Copper-pyrites, $CuFeS_2$.	Malachite, $CuCO_3 . Cu(OH)_2$.
Bornite, Cu_5FeS_4.	Chessylite, $2CuCO_3 . Cu(OH)_2$.
Tetrahedrite, Cu_3SbS_3.	Atacamite, $Cu_2Cl(OH)_3$.
Bournonite, $CuPbSbS_3$.	Dioptase, H_2CuSiO_4.
	Copper-vitriol, $CuSO_4 . 5H_2O$.

Copper-glance, or chalcocite, when quite pure contains 79·8 per cent. of copper and 20·2 per cent. of sulphur. Sometimes the copper is replaced in part by small amounts of iron or silver, but copper-glance is always one of the purest of copper ores. It contains a higher percentage of copper than any other ore except cuprite, but the latter does not occur so abundantly and in such large masses as copper-glance. The black, massive mineral with dull lustre and unattractive appearance little suggests the presence of such a high percentage of copper. This element may be readily detected by heating the mineral before the blowpipe with sodium carbonate on charcoal: a globule of metallic copper results, which is readily recognized by its malleability and reddish colour. The fused mass on the charcoal when moistened with water produces a black stain on a silver coin, proving the presence of sulphur. The mineral is soluble in nitric acid giving a bright green solution, which on the addition of ammonia in excess becomes deep blue; this reaction may be employed to detect the presence of copper.

The crystals (plate 11, figs. 1 and 2) have hexagonal forms, but in reality they are orthorhombic with a prism angle of very nearly 120° (actually 119° 35′). The apparent hexagonal pyramid combined with the basal pinacoid, shown in the plate and in text-figure 111, is a combination of a rhombic pyramid $z = \frac{1}{3}P$ and a brachy-dome $e = \frac{2}{3}P\infty$, together with the basal pinacoid $c = 0P$. The fact that the angle between the two faces z and z is not quite the same as the angle between the faces z and e proves that the pyramid is not a hexagonal pyramid: and this is sometimes also shown by the striations on the basal plane c, which when present are in one direction only, namely parallel to the edge between c and e. Like other orthorhombic minerals (e. g. dyscrasite, p. 90, and aragonite) with a prism angle of nearly 120°, copper-glance is frequently twinned on one or on two of the prism faces (plate 11, fig. 3), giving rise to stellate groupings; there may then be on the basal plane three sets of striations at nearly 60°, when the twinned crystal has a still closer resemblance to a hexagonal crystal. Interpenetration-twins on other planes also occur in crystals of copper-glance.

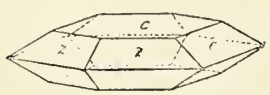

Fig. 111.
Crystal of Copper-glance.

The hardness of the mineral is 2—3, and it is somewhat sectile. Its specific gravity is 5·5—5·8. The colour and streak are blackish lead-grey; and the lustre is metallic, though often dull and tarnished.

Copper-glance is usually met with as compact masses, and is an important ore of copper. Distinctly crystallized specimens are found at only a few localities, the most notable of which are in western Cornwall, in the neighbourhood of Redruth and St. Just. It here occurs in veins of copper ore traversing granite and the adjacent clay-slate or "killas". Crystallized specimens were formerly abundant at Redruth (plate 11, figs. 1 and 2), and on this account the mineral has been named redruthite. In Germany, massive copper-glance occurs in veins with chalybite at Siegen in Westphalia. At Frankenberg in Hesse it forms the material of fossil plants (*Ullmannia Bronni*), which are there known as "ears of corn". It also occurs as a fine impregnation with bornite and copper-pyrites in the Kupferschiefer (copper-shale) of Mansfeld (plate 11, fig. 11) and Sangerhausen in Prussian Saxony. Massive copper-glance is found together with malachite in several of the copper mines of the Ural Mountains; for instance, in the Turjinsk mines near Bogoslovsk and at Nizhne-Tagilsk. Rich deposits are met with in south-west Africa, in Chile, and the United States. It is mined in the Anaconda lode in Montana; and at Bristol in Connecticut, besides the massive ore, fine crystals, very similar to those from Cornwall, are abundant. The twinned crystal shown in plate 11, fig. 3, is from the latter locality.

Covellite is often known as indigo-copper on account of its indigo-blue colour (plate 11, fig. 4). It usually occurs as a thin coating on other metallic ores of copper, to the alteration of which it owes its origin. Less frequently it is found in larger masses, whilst crystals are quite exceptional. The crystals have the form of hexagonal plates or scales with a perfect cleavage parallel to the basal plane, and on this plane the sub-metallic lustre is somewhat pearly in character. The thin plates are soft and flexible.

Although not an uncommon mineral, it rarely occurs in any quantity: as an indigo-blue powdery deposit it may be detected on the copper-pyrites of many localities. Larger amounts are found with copper-pyrites and iron-pyrites in the copper mines of Chile and Peru. Small crystals of the mineral were detected on Vesuvian lava by N. Covelli in 1839, and it is after this mineralogist that the name covellite was given.

Copper-pyrites, or chalcopyrite, with its characteristic brass-yellow colour and bright metallic lustre is one of the most readily recognizable of copper ores. It may perhaps at first sight be mistaken for iron-pyrites or native gold; but it is readily distinguished from the former by its deeper brass-yellow colour and by the fact that it can be scratched with a knife, whereas iron-pyrites cannot be so scratched. From gold it is readily distinguished by its brittleness and lack of malleability. It is the commonest of copper minerals and the most important ore of copper.

Chemically, it is a sulphide of copper and iron with the formula $CuFeS_2$, containing $34^1/_2$ per cent. of copper, $30^1/_2$ per cent. of iron, and 35 per cent. of sulphur. When heated in a bulb-tube, the mineral decrepitates, that is to say flies into fragments with a crackling noise; and further heating produces a sublimate of free sulphur on the sides of the tube. When roasted on charcoal before the blowpipe, the sulphur expelled from the mineral is oxidized to sulphur dioxide, which is readily recognized by its penetrating odour, and the mineral fuses to a magnetic globule; the magnetic character of the globule proves the presence of iron. If the globule be now moistened with hydrochloric acid and again heated, the blowpipe flame will be coloured first blue (due to copper chloride) and afterwards green (due to copper oxide). The three constituent elements of copper-pyrites may also be readily detected by warming the powdered

mineral in a test-tube with nitric acid: the mineral will be decomposed with the separation of sulphur and a green solution will be formed; on adding excess of ammonia to this, a deep blue solution characteristic of copper and a reddish-brown precipitate of iron hydroxide will be obtained. Since bornite contains the same elements, copper, iron and sulphur, it will of course give the same reactions as copper-pyrites, but these two minerals are readily distinguished by their colour.

Crystals of copper-pyrites are usually rather small and indistinctly developed. They belong to the tetragonal system with inclined or tetrahedral hemihedrism. The crystals on the specimen represented in plate 11, fig. 5, are combinations of two tetrahedra, $+\frac{P}{2}$ and $-\frac{P}{2}$, the former predominating. The crystals in fig. 6 are small, sharply-developed tetrahedra, and the large crystal in fig. 8 is a combination of the two tetrahedra with faces of about equal size. The small isolated crystal shown in figs. 7 *a* and *b* is a combination of a tetragonal scalenohedron and an acute tetrahedron: the form is represented more clearly in text-figure 112, where the faces χ are those of the scalenohedron and φ those of the tetrahedron.

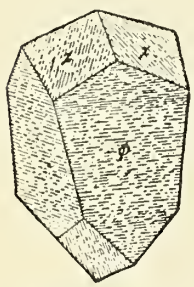

Fig. 112. Crystal of Copper-pyrites.

The forms of crytals of copper-pyrites are often obscured by twinning, and are not always easy to decipher. The twinning may be according to several laws; a repeated twinning on a face of the tetrahedron being perhaps the most common. The crystals shown in plate 11, fig. 9, are simple twins on a tetrahedron face, but the twinning is not clearly shown in the figure. Crystals of copper-pyrites are usually much grown together, either by regular twinning or in an irregular fashion (fig. 10), and it is consequently not easy to distinguish their forms.

In addition to crystals attached to the surface of the matrix, copper-pyrites very frequently occurs as compact masses embedded in the matrix or as large masses with no definite boundaries. Such material frequently displays a brilliant coloured tarnish on the surface, and for this reason it is known to miners as "peacock copper-ore". Freshly broken surfaces show the brass-yellow metallic colour of the mineral. Copper-pyrites sometimes forms a thin layer on the surface of tetrahedrite (plate 12, fig. 6), zinc-blende (plate 20, fig. 11) or galena (plate 16, fig. 6).

Copper-pyrites is readily attacked by weathering agencies, and under different conditions yields different alteration products. Simple oxidation produces the sulphates which are readily soluble in water, namely copper-vitriol and iron-vitriol. For this reason the water from copper mines is often charged with copper sulphate; and the copper is precipitated as cement copper by allowing the water to flow over scraps of metallic iron. Atmospheric weathering taking place the presence of carbon dioxide or of carbonates produces malachite or chessylite together with limonite. Or again, in the absence of carbon dioxide, copper-pyrites may be oxidized to a mixture of cuprite and limonite; and when this intermixture is intimate the product is known as tile-ore. In some cases, in the presence of reducing agents, native copper may result. These numerous processes which effect the alternation of copper-pyrites are especially active in the upper oxidized portions of the lodes of copper ore, that is in the gossan, and it is consequently here that the secondary copper minerals are found.

Copper-pyrites is mainly found in veins traversing clay-slates, especially in the neighbourhood of masses of igneous rock. It is often accompanied by chalybite (plate 11, figs. 5 and 10), quartz, zinc-blende and galena. It also sometimes occurs in beds with

iron-pyrites, as at Rammelsberg near Goslar in the Harz Mountains; or finely disseminated in sedimentary rocks, as in the Kupferschiefer (copper-shale) of Mansfeld in Germany. Being a common mineral, it has been found at very many localities; and here we select for mention only those localities which have yielded the better crystallized specimens or those which are remarkable for the extent of the deposit of ore.

The deposits of ore in the Rammelsberg near Goslar in the Harz Mountains have been worked since the year 972, and even at the present day they are highly productive. The ore here consists of a compact intermixture of copper-pyrites, iron-pyrites, zinc-blende, galena and barytes, and forms a stratum interbedded in sediments of Devonian age. The percentage of copper in this ore varies from 8—15½, and the annual production of copper and lead ore amounts to about 50,000 tons. Copper-pyrites is also present in the similar type of deposit at Rio Tinto in the south of Spain; particulars concerning this important deposit of ore will be given when we come to treat of iron-pyrites.

In the mineral-veins of the Harz Mountains, good crystals of copper-pyrites are often found; for example, with chalybite and quartz at Neudorf (plate 11, fig. 10), and at Clausthal (fig. 8). In the Zilla mine at Clausthal copper-pyrites forms a coating on crystals of tetrahedrite. Copper-pyrites is widely distributed in the Saxon Erzgebirge, though rarely in large amounts: very fine crystals have been found at Freiberg, and the specimen shown in fig. 9 is from Sadisdorf near Altenberg in Saxony. Veins of copper-pyrites are abundant in the slaty rocks of the Rhenish district, and good crystals come from the Heinrich mine at Littfeld.

In Cornwall and Devon, copper-pyrites is the more common ore of copper, and well crystallized specimens have been found in many of the mines, particularly in the neighbourhood of Redruth and St. Agnes; those from the Carn Brea mine near Redruth are often associated with chalybite (plate 11, fig. 5), and those from St. Agnes with clear, prismatic crystals of quartz. A peculiar variety from Cornwall, known as "blister copper-ore", has the form of mamillary and botryoidal masses.

Of the several localities for copper-pyrites in the United States, mention may be made of the French Creek mines in Chester Co., Pennsylvania, where crystals of scalenohedral habit (figs. 7*a* and 6) occur embedded in calcite. Together with these are found the crystals of iron-pyrites shown in plate 2, fig. 1, which, like the crystals of copper-pyrites, are completely developed on all sides. Small, sharply-developed tetrahedra of copper-pyrites are common at Joplin in Jasper Co., Missouri (plate 11, fig. 6); and sometimes these crystals are grouped in parallel position on crystals of zinc-blende. Large quantities of massive copper-pyrites are mined in the Anaconda lode in the State of Montana.

Bornite is often called erubescite, "purple copper-ore", or "variegated copper-ore", because it usually displays a coloured (purple, bluish or reddish) tarnish (plate 11, fig. 11). On a freshly fractured surface it has a bronze or pinchbeck-brown colour, and for this reason it is known to the Cornish miners as "horse-flesh-ore". These differences in the colour of fresh and of tarnished surfaces are especially characteristic of the mineral. The lustre is metallic. Bornite is composed of the same chemical elements as copper-pyrites, but these are combined together in different proportions. The blowpipe and qualitative chemical reactions are the same for the two minerals. Analyses of bornite have shown variations in the amount of copper present from 45 to 71 per cent. This wide variation is, however, to be explained by the presence of other minerals, more particularly copper-pyrites, intimately intermixed and intergrown with the bornite; even apparently pure crystals of bornite when broken

open will usually be found to enclose a nucleus of copper-pyrites. For many years the formula of the mineral has been given as Cu_3FeS_3, but a series of analyses recently made on carefully selected material have proved the true formula of the mineral to be Cu_5FeS_4, corresponding with 63·3 per cent. of copper, 11·2 per cent. of iron, and 25·5 per cent. of sulphur.

Crystals of bornite are of rare occurrence: they have usually the form of cubes with rough and curved faces, and often interpenetrating each other by twinning. Most of the crystallized specimens are from the copper mines in the neighbourhood of Redruth in Cornwall, but a few large isolated crystals have been found with native gold in the Tyrol. More usually, the mineral occurs as compact masses without crystalline form, and it is often found in sufficient amounts to be of value as an ore of copper. It occurs disseminated in the Kupferschiefer (copper-shale) of Mansfeld; the specimen represented in plate 11, fig. 11, shows the black slaty rock to the left and a band of bornite and barytes on the right. Considerable amounts of bornite are found in veins traversing diorite-schist at Kupferberg in Silesia. Other localities, where bornite is mined as an ore of copper, are Monte Catini in Tuscany, Acton in Canada, and Bristol in Connecticut.

The "Kupferschiefer", or copper-shale, which has been referred to several times in the preceding pages, is of great importance in Germany as a source of copper and silver. It is a black shale, coloured with bitumen, forming a stratum 0·5—0·6 metre (about 2 feet) in thickness, at the base of the German "Zechstein" formation of Permian age. This bed has a uniform character over a wide area, the principal development being in the Mansfeld basin between the Harz Mountains and the Thuringian Forest; it is also met with at Riechelsdorf near Bebra in Hesse-Nassau, and at Bieber near Gelnhausen. In it are frequently found the fossil remains of fishes which lived in the sea at the time that the copper-slate was deposited as a black mud in this area. The whole of the shaly material is impregnated with copper ore in a very finely divided state: the copper minerals present are mainly copper-glance, bornite and copper-pyrites. The shale contains 2—3 per cent. of copper, together with 0·01—0·02 per cent. of silver; so that a ton of copper obtained from it yields 5 kilograms of silver. The "Kupferschiefer" is not only the most important ore of copper in Germany, but it is also the chief source of silver in that country. In the year 1901 the production amounted to 695,321 tons of ore, from which was extracted 19,080 tons of copper and 99,132 kilograms of fine silver.

The series of strata of which the "Kupferschiefer" forms a part are not infrequently displaced by faults, and in the crevices of the fault-planes there has been a later deposition of cobalt and nickel ores (smaltite, niccolite, and chloanthite) with barytes and calcite, but with very little copper ores. It is clear that these cobalt and nickel ores must have been deposited by solutions rising up along the fault-planes from great depths in the earth's crust: but the origin of the copper in the "Kupferschiefer" itself is not so readily explained. It is probable, however, that the copper was precipitated from the sea-water at the same time that the black mud was collecting on the floor of an inland sea or a shallow gulf. The copper salts held in solution by the sea-water may have been derived by the weathering of pre-existing copper ores, or they may have been brought up by springs from unknown depths in the earth's crust.

Tetrahedrite is a mineral, or rather group of minerals, which varies considerably in chemical composition, though always referable to the same general formula. It is included under the old German term *Fahlerz*, meaning grey-ore, or grey copper-ore.

Although there are wide variations in the chemical composition, the crystalline form is always the same.

The crystals belong to the tetrahedral class of the cubic system, and they afford the best example of this type of symmetry; it being on this account that the name tetrahedrite was given to the mineral. The crystals on the specimen represented in plate 12, fig. 1, are a combination of the positive tetrahedron $+\frac{O}{2}$ with the negative tetrahedron $-\frac{O}{2}$, the six-sided faces of the former being large and bright and the triangular faces of the latter small and dull. The large crystal in fig. 3 shows faces of a three-faced tetrahedron in combination with the tetrahedron; in this figure the tetrahedron face on the left-hand side of the crystal is large, while on the right-hand side a tetrahedron face is wanting, but this is due simply to an irregularity in the development of the crystals, such as is frequently met with amongst minerals. The crystals in fig. 4 have the positive tetrahedron as the predominating form, the edges of which are bevelled by faces of the three-faced tetrahedron $\frac{2O2}{2}$ (as in text-figure 113), and its corners are replaced by three faces of the rhombic dodecahedron $\backsim O$ (as in text-figure 114). Similar faces are also present on the crystals in fig. 2, but on the actual specimen there are several other faces too small to be represented in the figure. The black crystals shown in fig. 5 have a rather different form: here the rhombic-dodecahedron predominates, the three-edged corners of which are replaced by faces of the tetrahedron.

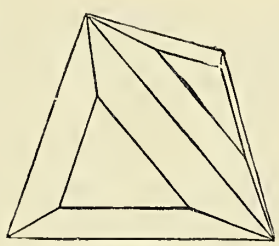

Fig. 113.

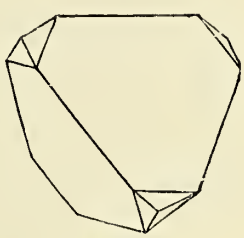

Fig. 114.

Crystals of Tetrahedrite.

The large crystal represented in fig. 6 of the same plate presents several points of interest. It does not show the true colour of the mineral, for it is completely covered with a shell of copper-pyrites, but this covering is so thin that the form of the crystal is still apparent. The three-faced tetrahedron predominates, its edges being truncated by the faces of the cube, and each of its corners replaced by three faces of the rhombic-dodecahedron. Penetrating the main crystal and standing out as a ridge on its surface is a second smaller crystal in twinned position, the twin-plane being a face of the tetrahedron. On the side of the crystal which is directed towards the front two of the faces of the three-faced tetrahedron are more largely developed than the third and the tetrahedron face is absent; but on the lower side (not shown in the figure) the tetrahedron face perpendicular to the twin-axis is largely developed, and the three faces of the three-faced tetrahedron are narrow. On one crystal in the lower part of fig. 4 there may also be seen a projecting ridge, due to a smaller crystal interpenetrating a larger one in twinned position.

The colour of tetrahedrite is steel-grey to iron black; the lustre is metallic and frequently very brilliant. Sometimes the crystals are slightly tarnished (fig. 4), or they may be dull and black. The mineral is usually quite opaque, but very minute splinters of some crystals transmit a blood-red colour. The streak, or colour of the powdered mineral, is usually black, but sometimes it has a reddish or purplish tinge. The hardness is slightly over 4 on the scale; and the specific gravity varies with the chemical composition from 4·4 to 5·1.

Typically, tetrahedrite is a compound of copper, antimony and sulphur, that is, a sulph-antimonite of copper, with the formula Cu_3SbS_3. The calculated percentage of copper corresponding to this formula is 46·8. The copper is, however, usually replaced to a lesser or greater extent by silver, iron, and zinc, and less frequently by mercury, lead, cobalt, etc. In some instances the silver is present to the extent of 30 per cent., and even when only a small percentage is present the mineral is a valuable ore of silver. Not only is the copper replaced in this way, but there may be a similar isomorphous replacement of the antimony by arsenic and less frequently by bismuth. In certain cases the antimony is entirely replaced by arsenic, and the formula then becomes Cu_3AsS_3, which corresponds to a calculated percentage for copper of 52·7. This is practically a distinct mineral, to which the name *tennantite* is applied, though still identical in crystalline form with tetrahedrite. Both tetrahedrite and tennantite are included under the general term fahlerz or grey copper-ore, the former being sometimes distinguished as antimony-fahlerz, and the latter as arsenic-fahlerz. Several other special names have been applied to minerals of this group when there is a predominance of certain elements, but such minerals are only to be distinguished by chemical analysis, and it is more convenient to refer to them collectively as fahlerz. Tetrahedrite being of far more frequent occurrence than tennantite, we have taken it as the typical example of the group.

When heated before the blowpipe, fahlerz readily fuses, and the reactions obtained will depend largely on the composition of the fragment tested. Antimony, if present, will produce a white sublimate on the charcoal, and arsenic will yield the characteristic odour of garlic. The roasted bead when moistened with hydrochloric acid will impart a blue colour to the flame, indicating the presence of copper. The presence of sulphur is also readily detected by fusing the mineral with sodium carbonate and moistening the fused mass on a silver coin.

Tetrahedrite occurs as crystals and masses in mineral-veins, and is usually associated with copper-pyrites, zinc-blende (plate 20, fig. 10), iron-pyrites, quartz (plate 12, fig. 4) and chalybite.

Fine crystals are met with in the veins near Clausthal in the Harz Mountains (plate 12, fig. 3); those from the Zilla mine being coated with copper-pyrites (fig. 6). Crystals rich in faces and often much fractured are found at Dillenburg in Nassau, and brilliant, sharply-developed crystals in the George mine at Horhausen in Rhenish Prussia. Specially large tetrahedral crystals are found at Botes in Transylvania, and a well-known locality for good specimens is Kapnik in Hungary. A variety of tetrahedrite containing mercury is found in the mercury mines of Rhenish Bavaria and at Schwarz in the Tyrol, whilst the large black crystals (fig. 5) from Kleinkogel, near Brixlegg in the Tyrol, are free from mercury. In Russia, a few crystals of tetrahedrite have been found in the Wassiljevski mines and at Beresovsk in the Ural Mountains, but here the mineral is not common.

Very fine groups of large crystals of tetrahedrite were formerly found in the Herodsfoot mine near Liskeard in Cornwall: the crystals are always thinly coated with copper-pyrites, which is either bright and brassy or has a brilliantly-coloured tarnish. The arsenical variety, tennantite, was formerly found in some quantity as small black crystals in several mines in the neighbourhood of Redruth in Cornwall. Tetrahedrite is also found at several localities in Chile, Peru, Bolivia and the United States; in Bolivia it is an important ore of silver.

Bournonite is a sulph-antimonite of copper and lead with the formula $CuPbSbS_3$. It thus contains the same elements as tetrahedrite with the addition of lead, and we

may consider two atoms of monovalent copper in tetrahedrite to be replaced by one atom of bivalent lead. The percentage chemical composition corresponding with the above formula is: 13% copper, 42·5% lead, 24·7% antimony, and 19·8% sulphur. The mineral is thus at the same time an ore of lead and of copper.

The crystals belong to the orthorhombic system, and are commonly tabular in habit. The single crystal shown on the matrix in plate 12, fig. 7, is represented in its ideal development in text-figure 115. The crystal is tabular parallel to the basal plane (*c*); there are two macrodomes (*o* and *x*) and one brachy-dome (*n*), and small faces of a pyramid (*u*). Simple crystals like the one figured are of rare occurrence; usually the crystals are much twinned on the prism faces, giving rise to numerous re-entrant angles (figs. 8 and 9). The flat tabular crystals with these numerous indentations on their edges somewhat resemble cog-wheels, hence the mineral is sometimes known as "cog-wheel-ore" or "wheel-ore".

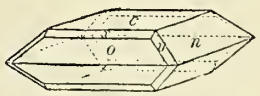

Fig. 115.
Crystal of Bournonite.

Bournonite is steel-grey in colour with a brilliant metallic lustre (fig. 8); sometimes the crystals have a dull black tarnish (fig. 9). Its hardness is about 3, being rather less than that of tetrahedrite, and its specific gravity 5·8. Before the blowpipe, it gives the same reactions as tetrahedrite, and also a yellow sublimate indicating the presence of lead.

Bournonite is not a mineral of very frequent occurrence; it is met with in mineral-veins in association with tetrahedrite, galena, zinc-blende, chalybite and quartz. The specimen represented in plate 12, fig. 7 is from Horhausen in the Coblenz district, Rhenish Prussia. Larger and thicker crystals are found at Neudorf in the Harz Mountains. The more typical "wheel-ore" is from Kapnik in Hungary and Nagyag in Transylvania. Fine, crystallized specimens were formerly found in Cornwall (figs. 8 and 9), in the Herodsfoot mine near Liskeard together with tetrahedrite, and in Wheal Boys at Endellion. It is also found in the Bolivian silver mines.

Cuprite. The sulphide ores of copper so far described are distinguished by their metallic lustre and opacity. On the other hand, the oxygen compounds of copper are transparent without a metallic lustre and they are brilliantly coloured, so that some of them at least find an application as semi-precious stones in addition to being ores of copper. The simplest oxygen compound of copper is the sub-oxide or cuprous oxide, Cu_2O, which contains 88·8 per cent. of copper, and is consequently the richest ore of the metal (with the exception of native copper). This is the mineral cuprite, also known as ruby-copper or as red copper-ore, on account of its characteristic red colour. The crystals (plate 13, figs. 1—3; plate 3, fig. 1) are transparent or translucent with a rich ruby-red or cochineal-red colour, and often a very brilliant adamantine to sub-metallic lustre, which sometimes gives them an almost lead-grey metallic appearance. On holding such a crystal up to the light, however, it will be seen to be red and transparent. The colour of the powder or streak is cochineal-red: this is seen in fig. 3, at spots where the crystals have been bruised. The brilliant, sub-metallic appearance of the crystals is connected with the very high refractive index (2·85) of the mineral, which is higher than that of diamond.

The crystals belong to the cubic system; they have the form of the simple cube (plate 13, fig. 3), or the simple octahedron, or various combinations of the cube, octahedron and rhombic-dodecahedron. Fig. 2 of plate 13 and text-figure 116 show the combination of the octahedron and cube, and fig. 1 and text-figure 117 that of the rhombic-dodecahedron and octahedron. A very remarkable form of growth of crystals of cuprite is presented by the variety known as chalcotrichite: here the crystals have

the form of very fine hairs, being enormously elongated in one direction; and the several hairs are aggregated in velvety tufts with a brilliant red colour.

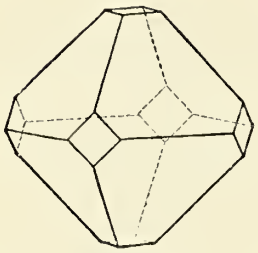

Fig. 116.

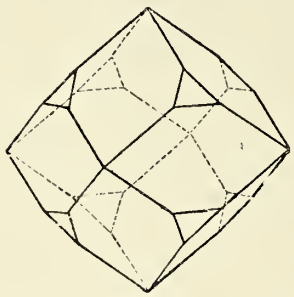

Fig. 117.

Crystals of Cuprite.

The hardness of cuprite is $3^1/_2$—4, and its specific gravity is 5·9. The crystals possess poor cleavages parallel to the faces of the octahedron and the cube. When the mineral is heated before the blowpipe on charcoal, a bead of metallic copper is readily obtained, and this is the simplest method of identifying the massive ore.

As already mentioned (p. 102), cuprite results from the alteration by weathering of copper-pyrites, and for this reason it is usually found in association with limonite (plate 13, figs. 1—3). By still further weathering in the presence of carbon dioxide and water, the cuprite itself is altered to malachite, as proved by the frequent occurrence of pseudomorphs of malachite after cuprite (plate 3, figs. 2—4; plate 13, fig. 4), which have been already described (p. 49). The alteration of cuprite to native copper is less frequent (plate 3, fig. 5). Being an alteration product of copper-pyrites, cuprite is usually met with in the upper oxidized portions of copper lodes, that is, in the gossany limonite of the "iron hat" of the lodes.

Good crystals of cuprite are found in Rhenish Prussia; the specimen shown in plate 13, fig. 1 is from Kaisersteimel (or Käuser Steimel) near Betzdorf; the capillary chalcotrichite is found at Rheinbreitbach. Isolated crystals developed on all sides are found embedded in clay at Chessy, near Lyons in France; but these crystals are usually partly or completely altered to malachite (plate 3, figs. 1—4; plate 13, fig. 4). Very fine, crystallized specimens were formerly found in abundance at Wheal Phoenix, near Liskeard in Cornwall (plate 13, figs. 2 and 3), and in the copper mines near St. Day. In Russia, excellent crystals have been found, together with massive cuprite, in the copper mines of Gumeshevsk, 56 versts ($7^1/_2$ geographical miles) south-west of Ekaterinburg, a locality which will be again mentioned under malachite. Crystals of cuprite are also found in the Medno-Rudiansk mine at Nizhni-Tagilsk in the Ural Mountains. Other localities are Damaraland in South-West Africa, where pseudomorphs of native copper after cuprite are also found; Arizona in the United States; and Chile.

Tenorite is the black oxide of copper, cupric oxide, with the formula CuO, and is of much less frequent occurrence than cuprite. As small black scales with a bright lustre, it is found in crevices in Vesuvian lava: but more often it is met with as a black earthy mineral to which the name melaconite has been applied. The latter when occurring in large masses is an important ore of copper; it is so found at the Ducktown mines in Tennessee, and formerly at Copper Harbour on Lake Superior in Michigan.

Malachite (plate 13, figs. 5—10) is the commonest of copper minerals, since at the earth's surface it is the most stable compound of copper, all other copper minerals when subjected to weathering agencies being converted in the course of time into green malachite. The patina, which as a thin green encrustation is to be seen on all ancient bronze remains, consists principally of malachite. The representation of a sky in a Swiss church was long ago painted blue with chessylite, but is now green, the chessylite having become altered to malachite.

Chemically, malachite is a basic carbonate of copper, containing besides copper the atmospheric constituents oxygen, carbonic acid and water. Its formula is $CuCO_3.Cu(OH)_2$, and when pure it contains 57·4 per cent. of copper. It is readily soluble in hydrochloric acid with effervescence, owing to the evolution of carbon dioxide, and a green solution results. When moistened with hydrochloric acid, it imparts a blue coloration to the flame of a Bunsen-burner. Heated on charcoal before the blowpipe, a fragment of the mineral readily yields a bead of metallic copper.

Crystals of malachite are monoclinic, but they are never distinctly developed, and such a twinned crystal as represented in the accompanying figure (fig. 118) is quite exceptional. The fine, needle-shaped crystals are usually aggregated into radiating tufts and brushes (plate 13, fig. 8). More usually, however, the mineral takes the form of mamillated, botryoidal or nodular masses with a smooth, rounded external surface, and a radially-fibrous internal structure. The form may be more or less globular (figs. 9 and 10) or kidney-shaped (reniform, figs. 5 and 7).

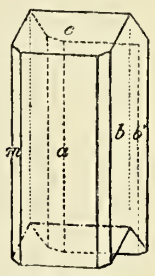

Fig. 118.
Twinned crystal of Malachite.

In addition to the radially-fibrous structure (fig. 7) shown on broken surfaces of nodular malachite, the material also exhibits a concentric-shelly structure (figs. 6 and 7). The concentric layers are alternately lighter or darker in colour, and more porous or more compact in texture. Each layer, seen as a band on the broken surface or on an artificially cut section, is uniform in thickness and envelops the inner layers; at a distance further from the centre the larger layers enclose two or more interior concentric systems. The whole structure thus presents a striking resemblance to the banded structure of agate; but while an agate has grown from the outside towards the inside, in malachite the direction of growth has been the reverse. In agate the innermost layer was the last to be formed, while in malachite the outermost layer is the latest.

The hardness of malachite is low (H. $= 3^1/_2 - 4$), so that the material is easily worked. The specific gravity is about 4. Being an aggregate of minute crystals, the material is opaque in the mass. In finely fibrous aggregates the lustre is sometimes distinctly silky; but otherwise the lustre is dull, although the mineral is capable of taking a good polish when worked.

As to localities for malachite, reference may be made to all of those which have been mentioned above for the various ores of copper. Here we will name only those which are of special importance.

Comparatively good crystals of malachite are found at Betzdorf in Rhenish Prussia. Pseudomorphs of malachite from Chessy, near Lyons in France, have been already mentioned: the crystals of chessylite from the same place are also often more or less altered to malachite (plate 14, fig. 1). The specimen shown in plate 13, fig. 9, is from Australia, probably from Burra-Burra in South Australia, where the mineral occurs in some abundance and of a quality suitable for cutting and polishing: similar material is also found in Queensland and New South Wales. That shown in fig. 10 is from Morenci in Arizona; and large masses are common in the Copper Queen mine in the same State. The remaining four specimens figured in plate 13 are all from the Ural Mountains, a region which has long been famous for its malachite. The largest and best masses have been yielded by the copper mines of Gumeshevsk, situated 56 versts (about 60 kilometres) south-west of Ekaterinburg on the western slopes of the Urals. A detailed description of this locality has been given by Gustav Rose, who in company with Alexander von Humboldt visited the Urals in 1829. These mines

have been worked for centuries, and they have yielded nodular masses of malachite weighing 160 kilograms or even more; whilst the weight of the largest block of malachite met with has been given as 2800 kilograms, or nearly three tons: a portion of this mass is preserved in the collection of the Institute of Mines at St. Petersburg. The masses of malachite are here found embedded in a red clay, and in association with cuprite and native copper. At the present day these mines are no longer worked. A similar occurrence of malachite is that of the Medno-Rudiansk mine at Nizhni-Tagilsk in the northern Urals, from whence came the specimen shown in fig. 7. In this mine was discovered in 1836 the largest mass of malachite on record: it measured $17^1/_2$ feet long, 8 feet across and $3^1/_2$ feet in height, and was estimated to weigh 25 to 30 tons. In this, and other mines in the neighbourhood of Nizhni-Tagilsk, the nodules of malachite are embedded in a clayey rock and are accompanied by other ores of copper. It is this district which at the present day yields most of the malachite of value for polishing.

The larger and better marked pieces of malachite are cut and polished in the lapidary works at Ekaterinburg, being made into vases, bowls, table-tops and many other objects and small ornaments. Elaborate ornaments of malachite, in many cases the gift of the Czar of Russia, are to be seen in many museums. The larger objects, such as table-tops and columns, do not consist of solid malachite but are veneered with the mineral. Most of the malachite of the copper mines of the Urals is found as small nodular masses, often not larger than a pea; such material is useless for cutting, but it is of value as an ore of copper, and it is consequently smelted with the other copper ores. The annual production of the Medno-Rudiansk mine amounts to 1240 tons of copper.

Chessylite, or azurite, contains the same chemical elements as malachite, but these are combined in different proportions. Its formula is $2CuCO_3 . Cu(OH)_2$, corresponding with 55·2 per cent. of copper. Both minerals behave the same towards chemical reagents, but they are strikingly different in colour, malachite being green and chessylite blue. The name azurite, often applied to this mineral, has reference to its blue colour, which is so intense that only thin crystals and splinters are transparent. Unlike malachite, chessylite is often found as crystals, but as these are usually confusedly grouped together their form is not always distinct. The crystals belong to the monoclinic system, and are usually bounded by a large basal plane (*c*, fig. 119), a vertical prism (*m*), a pyramid (*k*), and a brachy-dome (*l*). Owing to the unequal development of different faces of the same form, the crystals are usually more or less distorted and irregular (plate 14, figs. 1 and 2). The crystals are sometimes of comparatively large size, but as a rule they are quite small and closely aggregated, forming a dark blue crystalline crust. Sometimes the mineral forms an earthy coating on other minerals; the colour is then lighter and may be a brilliant sky-blue. Or again, it may occur, together with malachite, as an impregnation in rocks; for example, in the Triassic sandstone of the Eifel district, and in the Permian sandstone of the Kargalinsk Steppes in Orenburg and other places in Russia.

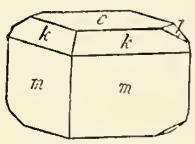

Fig. 119.
Crystal of Chessylite.

The hardness of chessylite is $3^1/_2$—4, and its specific gravity 3·8. Chessylite owes its origin to the decomposition of other copper minerals, more particulary tetrahedrite; and it is itself readily altered to malachite, with which it is invariably associated.

A noted locality for fine crystallized specimens of chessylite is that from which the mineral takes its name, namely Chessy, near Lyons in France (plate 14, fig. 1). Good crystals have also been found at Zmeinogorsk in the Altai Mountains, and in the

Copper Queen mine in Arizona (fig. 2), but perhaps the largest and most brilliant crystals are those more recently obtained from Broken Hill in New South Wales. At the Copper Queen mine in Arizona it is found in sufficient quantity to be a valuable ore of copper: it here occurs with malachite in limonite, and has clearly resulted from the decomposition of sulphide ores of copper in the upper part of the lode.

In addition to being used as an ore of copper, chessylite is powdered and used as a colouring material under the name "mountain-blue". This is, however, now almost completely replaced by the blue pigment known as "lime-blue", which is prepared artificially from copper nitrate and burnt lime. In the same way the "mountain green" furnished by malachite is replaced by an artificially prepared colouring material.

Atacamite. This mineral somewhat resembles malachite in its colour, which is, however, a rather darker green; and like malachite it sometimes occurs in fibrous and nodular masses. It also frequently occurs as well-developed orthorhombic crystals of prismatic habit. A magnificent crystal of an unusually large size is represented in plate 14, fig. 5; the original specimen is in the Stuttgart Museum. The habit is prismatic and the prism faces are striated parallel to their length; the crystal is terminated by a dome and a pyramid (the dome being seen in the figure as one large face to the front, and the pyramid as smaller faces on either side of the dome face). The smaller crystal represented in fig. 6 has exactly the same forms, only the crystal is turned round so that the two dome faces slope away to the left and the right. More usually, the crystals are smaller than in the two examples just mentioned, and they are aggregated in irregular groups as in fig. 7. With still smaller crystals there may be all degrees of transition to columnar and fibrous aggregates.

Fibrous aggregates of atacamite may at first sight be mistaken for malachite; but the two minerals are readily distinguished by the fact that atacamite does not effervesce when moistened with a drop of hydrochloric acid. Further, atacamite imparts, without the addition of hydrochloric acid, a blue coloration to the Bunsen-flame, thus proving the presence of copper and chlorine. When a fragment of atacamite is heated in a bulb-tube, water is given off and condenses on the sides of the tube. The mineral is thus easily proved to contain copper, chlorine and water. Quantitative chemical analysis shows the presence of copper 59·4, chlorine 16·6, and water 12·7 per cent., a total of 88·7 per cent. The difference between this total and 100 per cent. is accounted for by oxygen, as shown in the formula $Cu_2Cl(OH)_3$ or $Cu(OH)Cl \cdot Cu(OH)_2$. Atacamite is thus a hydrated oxy-chloride of copper.

Like other copper minerals, atacamite becomes altered by weathering to malachite; and when partially altered in this way it will effervesce in contact with acid, and will when heated alone impart a blue colour to the flame.

Atacamite is found at only a few localities. It is of common occurrence in the Desert of Atacama in Chile, and on this account it receives its name: at Remolinos and Ojancos it occurs in large quantities as fibrous aggregates in veins, and at Sierra Gorda brilliant crystals are not uncommon. The larger crystals, such as those figured in plate 14, are all from the Burra-Burra copper mines, north of Adelaide in South-Australia. The mineral was discovered here in 1845, and large amounts were mined until the exhaustion of the deposit in 1877. Formerly in Chile, atacamite was ground to a sand and sold under the name "arsenillo", and was employed for the purpose for which blotting paper is now used.

Dioptase, although a rare mineral, presents several points of interest and deserves some mention here. Its brilliant emerald-green colour at once suggests that it contains copper; but it is to be remembered that such a colour does not necessarily imply the

presence of copper, emerald and green garnet being, for example, free from copper. The presence of copper in dioptase may be readily demonstrated by moistening the mineral with hydrochloric acid and heating in the Bunsen-flame, when a blue colour will be imparted to the flame; or by heating the mineral before the blowpipe on charcoal with sodium carbonate, when a globule of metallic copper is obtained. When warmed in a test-tube with hydrochloric acid, the mineral is decomposed with the separation of a jelly consisting of silica and the production of a green copper solution. Heated strongly in a bulb-tube, the mineral gives off water. The constituents of dioptase are therefore copper, silica and water, and these are combined on the proportions given by the formula H_2CuSiO_4, corresponding to 41·2 per cent. of copper.

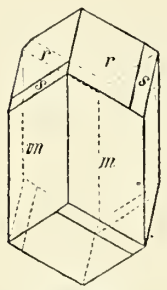

Fig. 120.
Crystal of Dioptase.

The mineral usually occurs in bright, well-formed crystals, though these are often of small size. They belong to the rhombohedral-tetartohedral class of the hexagonal system. The crystals always show the faces of a rhombohedron (*r*, fig. 120) combined with the hexagonal prism of the second order (*m*); in addition to these faces there are sometimes narrow faces (*s*) of a rhombohedron of the third order truncating alternate edges between the rhombohedron *r* and the prism *m*. The crystals have a vitreous lustre; they are usually translucent, but sometimes transparent. The hardness of the mineral is 5, and its specific gravity 3·3.

The two specimens of dioptase figured in plate 14, figs. 3 and 4, are both from the best known locality for this mineral, namely the hill of Altyn-Tübe in the Kirghiz Steppes, 300 kilometres south of the Kariakovsky outpost in Siberia. The crystals are attached, together with calcite, to the surfaces of crevices in limestone. Other localities are the gold-washings in the government Yeniseisk in Siberia, Copiapó in Chile, Clifton in Arizona, and more recently good crystals have been found at Mindouli in the French Congo.

Dioptase cannot be said to be a mineral of any economic importance, since it does not occur in sufficient quantity to be mined as an ore of copper. Most of the crystals are preserved in mineral collections, and occasionally a clear transparent crystal may have been cut and passed off as an emerald.

In addition to dioptase, there is another hydrated silicate of copper, which occurs in nature as the mineral *chrysocolla*. This forms compact masses and is not crystalline. In appearance it somewhat resembles malachite, but the colour may vary from a light to a dark green and is sometimes a bluish-green. It is mined with other ores of copper, and compact pieces of a good colour have occasionally been cut as a semi-precious stone. Localities are Dillenburg in Nassau, Bogoslovsk in the Ural Mountains, and Chile.

Copper-vitriol, or chalcanthite, is readily soluble in water, and for this reason it is but rarely met with as a mineral: it would not be readily deposited from a natural solution and when deposited it would always be liable to be carried away again. The well-known copper-vitriol of commerce is an artificial product. As the name implies, it is a compound of copper and vitriol, that is sulphuric acid; water of crystallization is also present, and the formula for the mineral, as well as for the artificial product, is $CuSO_4.5H_2O$. Crystals (plate 11, fig. 9) belong to the triclinic system with acute angles between the faces, but well-formed crystals are quite rare in nature, though they may be readily obtained artificially from a solution of copper sulphate. The colour is bright blue and the crystals are transparent to translucent.

This mineral occurs at Rammelsberg near Goslar in the Harz Mountains, at Rio Tinto in Spain, and at other localities. As already mentioned, it is one of the products of the weathering of copper-pyrites, and it is frequently present in solution in the waters of copper mines. The water pumped up from the mines is allowed to flow over scrap iron, which precipitates the copper in a metallic form known as cement copper.

Other copper sulphates are known in nature as minerals, but these are basic salts insoluble in water. The most important is the mineral *brochantite*, which has the formula $CuSO_4 . 3Cu(OH)_2$. Others of rarer occurrence are langite and herrengrundite.

Several mineral phosphates and arsenates of copper are known, but they are of rare occurrence and their crystals are usually quite small. Libethenite, $Cu_2(OH)PO_4$ and olivenite $Cu_2(OH)AsO_4$ are perhaps the more common, but here we shall briefly describe only *euchroite*, since this occurs in rather larger and distinct crystals (plate 14, fig. 8). Euchroite is a hydrated basic arsenate of copper with the formula $Cu_2(OH)AsO_4 . 3H_2O$. It crystallizes in the orthorhombic system, and is found at Libethen in Hungary.

Uses of copper. — Metallic copper, either in a pure state or alloyed with other metals, has been extensively used for many purposes from very remote times.

Unalloyed copper is used for the construction of kettles, stills, worms, for wire, sheets and plates for sheathing ships, and for many other purposes. It is of importance for the construction of all kinds of electrical apparatus, since, next to silver, it is the best conductor of electricity. The electrical conductivity increases with the purity of the metal, and the copper deposited by the electrolytic method in the purest. The daily production of copper by this method amounts to 800 tons, of which $86^1/_2$ per cent. is contributed by the United States.

Alloys of copper are of different composition according to the uses to which they are to be put. The German copper coinage contains 95 per cent. of copper alloyed with 4 per cent. of tin and 1 per cent. of zinc: that of most other European countries (Russia, Sweden, the United Kingdom, and the Romanic countries) contains $3^1/_2$ per cent. of tin and $1^1/_2$ per cent. of zinc. The German "nickel" coins consist of an alloy of 75 per cent. of copper with 25 per cent. of nickel.

Bronze is a copper alloy which has been used from very early times. It consists essentially of copper and tin, but there are several varieties differing somewhat in composition. Art-bronze or statuary-bronze, such as is used for statuary and various ornaments, consists of 86·6 parts of copper, 6·6 parts of tin, 3·3 parts of lead and 3·3 parts of zinc. When fused, it flows readily and takes a good impression of the mould; it can be readily worked, and in the course of time it acquires a dull green oxidized surface — the so-called patina. Gun-metal or steel-bronze consists of 92 parts of copper and 8 parts of tin; it was formerly used for gun-barrels. A bronze of very similar composition (91·8 parts of copper and 7·5 parts of tin) was used at the time of the second settlement of Troy for chisels, and another Trojan bronze (containing 87 parts of copper and 10·6 parts of tin with a little lead, arsenic and antimony) served for dagger blades. Bell-metal contains on the average 78 parts of copper with 22 parts of tin. Phosphor-bronze consists of 90 parts of copper, 9 parts of tin, and 0·5 to 0·75 parts of phosphorus; it is harder than the other varieties of bronze, though still ductile, elastic and tenacious. Slight variations in the composition of phosphor-bronze give alloys with different characters according to the uses to which they are to be put; it is used for the same purposes as gun-metal, bell-metal and art-bronze, and for several special purposes where the metal is subject to sudden and violent shocks. Aluminium-bronze contains 90 to 95 parts of copper and 5 to 10 parts of aluminium; it has a gold-yellow colour and does not readily tarnish, and is consequently used for watch-cases and similar

objects. Brass is another important alloy, containing 60 to 70 parts of copper and 30 to 40 parts of zinc; the greater the amount of copper present, the less ductile and darker in colour is the alloy. An alloy containing 85 parts of copper with 15 parts of zinc is called tombac or red brass. German silver or nickel-silver is an alloy of a silver-white colour consisting largely of copper with nickel and either zinc or tin. "Alfenide" and "christofle" are names given to nickel-silver containing small amounts of silver. Bronze paints contain 81—99 parts of copper.

Of the *salts of copper*, copper sulphate is the one most extensively used. When an electric current passes through a solution of a copper salt, the copper is deposited in the metallic state; in this manner electrotypes are made, and the pure copper so deposited is much used for electrical purposes. Solutions of copper sulphate and lime are used in horticulture for destroying blight. Copper sulphate is also used in the manufacture of paints and printing inks: treated with a solution of lime it gives the so-called lime-blue; with alkali and common salt the so-called Bremen blue; and when ground with oil it gives Bremen green. Another green pigment, known as Scheele's green, is a compound of copper and arsenious acid, and is consequently extremely poisonous. The uses of malachite for ornamental purposes and of chessylite as a pigment have already been mentioned.

In the *production of copper* the United States of North America is far ahead of all other countries. The veins and beds of copper ore are here extremely large and rich. The richest vein is the Anaconda lode in Montana; this has a width of 13 metres (40 feet) and in the year 1900 had been worked to a depth of 600 metres. During the years 1897 and 1898 it yielded almost half a million tons of ore, consisting of copper-glance and copper-pyrites, from which more than 62,000 tons of copper was extracted. The massive ore contains almost 35 per cent. of copper, whilst the ore together with the gangue contains 10 per cent., the average for the whole ore being 16 per cent. of copper. In contrast with this, the European copper ores are poor in copper, the abundant copper ore of Rio Tinto containing only 3 per cent. of copper.

The following table gives the amounts of copper, in tons of 2240 lb., produced in the more important countries. The total production for the whole world in the year 1901 amounted to 528,327 tons, and in 1905 to 689,277 tons.

	1901 Tons.	1905 Tons.		1901 Tons.	1905 Tons.
North America:			**Africa** (*South*):	6 400	2 300
United States	267 400	389 122	**Europe:**		
Mexico	23 795	68 907	*Spain and Portugal:*		
Canada	18 000	21 248	*Rio Tinto*	35 348	32 280
Newfoundland	2 000	2 280	*Other mines*	18 273	12 530
South America:			*Germany:*		
Chile	30 000	29 165	*Mansfeld*	18 780	19 565
Peru	9 520	8 625	*Other mines*	2 940	2 595
Bolivia	2 000	2 000	*Russia*	8 000	8 700
Asia:			*Italy*	3 000	2 950
Japan	27 475	35 910	*Norway*	3 375	6 305
			Austria-Hungary	1 015	1 325
Australia	30 875	36 560	*United Kingdom*	532	500

Mercury Ores.

Mercury, or quicksilver, holds a unique position amongst metals in being the only one which is liquid at the ordinary temperature. It occurs free in nature, but only rarely and never in large quantities; more usually it occurs in chemical combination with other elements. When combined with sulphur we have the mineral cinnabar, which is the only ore of the metal. Less frequently it is combined with silver as amalgam, and with chlorine as calomel. Mercury is also present in some varieties of tetrahedrite and in some other rarer minerals.

Native mercury, or virgin quicksilver as it is sometimes called, is found as small liquid globules, with a tin-white colour and brilliant metallic lustre, in rock crevices (fig. 1, plate 15), and is usually associated with cinnabar. It is known from Moschellandsberg (or more correctly Landsberg near Obermoschel) in Rhenish Bavaria, from Idria in Carinthia, from Almaden in Spain, from California, and other localities of mercury ores. Since this is a mineral of rare occurrence and the metal is always obtained from cinnabar, we shall defer any mention of its properties and applications till we have dealt with the ore itself.

Amalgam is a mixture or alloy of mercury with other metals: in nature these may be either gold or silver, the latter being by far the more common. As a mineral, the name amalgam is limited to the mixtures of mercury and silver, that is to silver amalgam. This (figs. 2 and 3, plate 15) is sometimes found as brilliant crystals belonging to the cubic system, which are often well developed and bounded by numerous faces. Fig. 2 represents a rhombic-dodecahedral crystal, and fig. 3 represents the more usual massive form of the mineral.

The colour of amalgam is tin-white, and the lustre is brilliant and metallic; the mineral has in fact much the appearance which we should expect frozen mercury to show. The hardness is 3, and the specific gravity about 14, but varying with the relative amounts of mercury and silver.

The best known locality for amalgam is Moschellandsberg in Rhenish Bavaria, from whence finely developed crystals have been obtained; these mines are, however, no longer worked, and the crystals now command a high price. Dendritic amalgam has been found in the Friedrichssegen mine near Ems in Nassau. Amalgam is, however, a mineral of quite rare occurrence and it has been met with at only few localities.

Cinnabar is a compound of mercury and sulphur with the formula HgS. It is practically the only ore of mercury, and when pure contains 86·2 per cent. of this metal; usually, however, owing to the presence of admixed impurities, the content of mercury falls below the theoretical amount. The characteristic cinnabar-red or vermilion colour is only shown where the mineral is finely granular or earthy; crystals are dark red in colour, and transparent with an almost metallic lustre. The crystals belong to the rhombohedral system, and the predominating forms are usually a rhombohedron and the basal plane. The large crystals represented in fig. 4, plate 15, show a dull basal plane and bright faces of the rhombohedron; in figs. 5 and 6 the rhombohedral faces are striated parallel to their intersection with the basal plane. Larger and better crystals than those figured on plate 15 are of extremely rare occurrence. The crystals may occur with quartz grown on a matrix of quartzite (fig. 4), or on a matrix of granular cinnabar (fig. 5). They possess perfect cleavages parallel to the six faces of the hexagonal prism of the first order; a cleavage fragment is represented in fig. 7. The mineral has a specific gravity of 8, and a low degree of hardness (H. = 2).

The optical characters of cinnabar present features of special interest: the indices of refraction and the double refraction are both high, and the crystals have the property of rotating the plane of plane-polarized light, the rotary power being about fifteen times as great as in quartz. A thin plate parallel to the basal plane of a crystal of cinnabar therefore gives in the polariscope in convergent light an interference-figure like that represented in fig. 2, plate 4. The refractive index for the ordinary ray is 2·858, and for the extraordinary ray 3·201: the refractive index is thus greater than that of diamond, and the double refraction stronger than that of calcite, whilst the rotary power greatly exceeds that of quartz.

When heated before the blowpipe on charcoal, pure cinnabar is completely volatilized. Heated alone in a glass tube closed at one end it gives a black sublimate of mercury sulphide, but if mixed with anhydrous sodium carbonate small globules of metallic mercury condense on the sides of the tube.

As already mentioned, crystallized cinnabar is of comparatively rare occurrence; more usually the mineral is found as granular (fig. 9), columnar (fig. 10), or compact (fig. 8) aggregates. Frequently also, it occurs intermixed with clay, as in hepatic cinnabar, so called because of its liver-brown colour; or mixed with carbonaceous matter, and then known as inflammable cinnabar. The so-called "coral-ore" (German, Korallenerz), (fig. 11), found at Idria as black masses, is a curved lamellar variety of hepatic cinnabar containing admixed clay and carbonaceous matter. These mixtures have little of the appearance of cinnabar or mercury ore, but the presence of mercury in them may be readily proved by the tests mentioned above.

Cinnabar is found in mineral-veins and as an impregnation in rocks. It is often associated with younger volcanic rocks (trachyte and basalt), and no doubt has been brought up from the greater depths of the earth by hot springs connected with volcanic outbreaks. At the present day cinnabar is being deposited by thermal waters in the mercury mines at Sulphur Bank in California.

The most extensive of all known deposits of mercury ore are those of Almaden in Spain (four of the specimens figured on the plate are from this locality). It is said that the Greeks worked mercury ore here 700 years before Christ; the deposits were also worked by the Romans and mercury was extracted by them from the ore. Until recently, Spain has been the principal mercury-producing country of the world, but lately the United States have taken the first place. The next most important European locality is Idria in Carniola (from whence is the "Korallenerz" shown in fig. 11); others are Monte Amiata in Tuscany (fig. 8); Mount Avala near Belgrade in Servia; and the neighbourhood of Nikitovka in the district of Bachmut, government Ekaterinoslaw, Russia. The mercury mines in Rhenish Bavaria yielded in former years not only cinnabar (fig. 10), but also native mercury (fig. 1) and amalgam (figs. 2 and 3), but they have long ago been exhausted. Small amounts of granular cinnabar (fig. 9) have been found in a mine at Hohensolms, near Giessen in Hesse. Curiously, cinnabar, or any other mineral containing mercury, has never been found in the British Isles.

California is rich in cinnabar along a zone 500 kilometres in length in the Coast Ranges. The most important mines are those of New Almaden, and others are situated at New Idria, Sulphur Bank, and Knoxville. In Mexico the principal localities for mercury ores are Guadalcazar and Huitzuco in the State of Guerrero. In Peru the cinnabar mines at Huancavelica were at one time of considerable importance. Recently, extensive deposits of cinnabar have been worked over a wide area in Kwei-chou and other provinces in central China; from this region large and magnificent twinned crystals, having the form of interpenetrating rhombohedra, have been obtained.

Applications. — Being a liquid metal possessed with peculiar properties, mercury has many important applications. Its property of combining with other metals to form amalgams is utilized for separating finely divided gold and silver from other minerals. This process of collecting gold by amalgamation was described long ago by Pliny, and it is still used to the present day, though the cyanide process is gradually replacing it (see under gold, p. 75). Tin amalgam is used for silvering mirrors; gold amalgam for gilding; and various other amalgams are employed in dentistry. The use of pure mercury for thermometers and barometers is well known. Mercury thermometers can, however, be used for only a limited range of temperature, since at —39·5° C. the metal freezes, crystallizing in cubic forms as does the mineral amalgam; and it boils at 360° C. Owing to its high specific gravity, namely 13·595 at 0° C., and to the fact that when pure it remains unaltered in the air at the ordinary temperature, mercury is much used in physical and chemical apparatus of various kinds.

The salts of mercury are extensively used in medicine, and are extremely poisonous. The compounds with chlorine, calomel (HgCl) and corrosive sublimate ($HgCl_2$), are the commonest salts. Pure mercury sulphide, HgS, artificially prepared from metallic mercury and sulphur, is the pigment known as vermilion. Fulminate of mercury ($C_2N_2HgO_2 + H_2O$) is used for making percussion caps.

The amount of the production of mercury is usually stated in "flasks", the weight of mercury in a flask being 28·54 kilograms, and its value about £9 10s. to £10. In the year 1901 the production in Spain amounted to 864 metric tons (of 1000 kilograms), in the United States 992, Austria 550, Mexico (in 1900) 335, Russia 340, and in Italy 220 metric tons.

Lead Ores.

As a native metal, lead is of rare occurrence, and it is of no importance either as a mineral or as an ore of lead. It has been found at only a few localities as thin plates coating other minerals, and the only interest that it presents lies in the fact that lead does occur in nature in the metallic form.

By far the most important ore of lead is galena, all other lead-bearing minerals being of quite secondary importance as ores of the metal. Galena is a compound of lead and sulphur, being sulphide of lead with the chemical formula PbS. Closely allied chemically to this are the rare minerals clausthalite and altaite, which are selenide of lead, PbSe, and telluride of lead, PbTe, respectively. Of sulphur compounds containing lead, several are known as minerals, but they are of comparatively rare occurrence: the more important are the following:

Sartorite, $PbAs_2S_4$.	Dufrenoysite, $Pb_2As_2S_5$.
Zinckenite, $PbSb_2S_4$.	Plumosite, $Pb_2Sb_2S_5$.
Galenobismutite, $PbBi_2S_4$.	Cosalite, $Pb_2Bi_2S_5$.
Jamesonite, $(Pb, Fe)_7Sb_8S_{19}$.	
Bournonite, $CuPbSbS_3$.	

Bournonite has already been described under the ores of copper (p. 106), and zinckenite is the only one that need be briefly mentioned in the following pages.

By the action of various oxidizing solutions on these sulphur compounds of lead, and particularly on galena, secondary minerals are formed. These are oxygen compounds of lead; they are often transparent and brilliantly coloured, and are characterized by their

high refrangibility for light. Some of them, when they occur in sufficiently large quantities are of importance as ores of lead. The more important of these secondary lead-bearing minerals are the following: —

Cerussite, $PbCO_3$.	Crocoite, $PbCrO_4$.
Phosgenite, $PbCO_3 . PbCl_2$.	Wulfenite, $PbMoO_4$.
Anglesite, $PbSO_4$.	Pyromorphite, $3Pb_3(PO_4)_2 . PbCl_2$.
	Mimetite, $3Pb_3(AsO_4)_2 . PbCl_2$.

These minerals are collected together here in our discussion of lead ores because they all contain lead as an important constituent. If, however, we were to group them according to the acid, as is done in the chemical system of classification in the text-books on mineralogy, we should see that cerussite is closely related in the form of its crystals to aragonite ($CaCO_3$), anglesite to barytes ($BaSO_4$), and pyromorphite and mimetite to apatite ($3Ca_3(PO_4) . CaCl_2$).

Galena, or lead-glance, with its metallic lustre and dark colour, is a typical representative of the glances, and for this reason it was formerly referred to simply as glance. It is not only the most abundant of lead ores, but also the richest in lead, containing 86 per cent. of the metal. Silver is almost invariably present in small quantity (rarely more than 0·01—0·5 per cent.), so that galena is at the same time an important ore of silver.

Crystals of galena belong to the cubic system, and the most usual form is a combination of the cube and octahedron (plate 16, figs. 1, 2 and 11). Sometimes the octahedral faces are quite small (fig. 2) or they may be altogether absent; or again they may be larger, as in the cubo-octahedron represented in plate 19, fig. 6; whilst in plate 16, fig. 4, the octahedron predominates over the cube. Finally, though less commonly, we may have crystals of galena bounded only by faces of the octahedron. The octahedral crystals represented in plate 16, fig. 3, have, on close inspection, the appearance of being built up of numerous minute cubes, and in the direction of the cube faces they give a shimmered reflection of light, with here and there bright reflections from the cubic cleavages. An example of a distorted combination of the cube and the octahedron is shown in fig. 7, plate 16, which represents a crystal with the same forms and from the same locality, namely the Gonderbach mine at Laasphe in Prussia, as the crystal shown in fig. 4 of the same plate. Here the cube planes at the side are largely developed, especially in the vertical direction, whilst that at the top of the crystal is absent; the form has then the appearance of a tetragonal prism of the first order in combination with a pyramid of the second order. The material has been supplied from one side, and the growth of the crystal has consequently taken place mainly in that direction.

Another peculiar form of growth of a galena crystal is illustrated in fig. 8. The larger central cubo-octahedron had apparently finished its growth, when there was a later deposit of crystallized galena in parallel position on the corners; this later growth having the form of small cubo-octahedra flattened parallel to the cube faces on which they grew. Finally, the parallel growth of crystals was coated over with a thin crust of copper-pyrites.

Minute octahedral crystals are sometimes grouped in lines in three directions at right angles along the three cubic edges, giving rise to a reticulated structure, as represented in fig. 7, plate 2. A similar structure, but with the secondary branches inclined to the main branches at angles of 60°, is shown in fig. 9 of plate 16.

Finally, the so-called "plates" or "fused" crystals represent another kind of distortion met with in crystals of galena, specially fine examples of which are found in the Gonderbach mine at Laasphe. The crystal shown in fig. 10, plate 16, is tabular in the direction of one pair of parallel octahedral faces, and is bounded at the edges by narrow

faces of the cube and the octahedron. Running across these large octahedral planes at the front and the back of the crystal are to be seen fine suture lines indicative of twinning. A portion of the crystal may be considered to have been rotated through an angle of 180°, so that the front face comes into coincidence with the back face and the back face in coincidence with the front. The twinning is here quite analogous to that previously described for the crystallized plates of gold and silver (p. 76), and frequently the small triangular elevations and pits, placed in reversed positions on opposite sides of the suture line, may be detected on these plates of galena. Tabular crystals of galena are not always so sharply developed as in the specimen here figured; usually their faces are curved and their edges rounded, and the crystals have then quite the appearance of having been partially fused. These "fused" crystals of galena owe their form, however, to pecularities of growth, for we know that they have been deposited in the mineral-veins from an aqueous solution and that they have not subsequently been exposed to any high temperature.

All the varied forms of galena crystals which we have so far considered are bounded solely by the octahedron and the cube, and although some of them appear at first sight to be irregular they may be seen on closer inspection to conform with the true symmetry of the mineral.

Other forms are not very common. In figs. 5 and 6, plate 16, we see, in addition to the cube and octahedron faces, other faces rounding the edges of the octahedron. Here each edge of the octahedron is replaced by three narrow faces, a face of the rhombic-dodecahedron in the middle and on either side faces of the three-faced octahedron with the symbol 2O. On other crystals, the edges between the cube and the octahedron faces may be replaced by faces of an icositetrahedron, though such a form is of rare occurrence in galena.

An important character of galena, and one by which the mineral may always be readily identified, is the perfect cleavage in three directions parallel to the faces of the cube. On the cleavage surfaces the lustre is always brilliant and metallic with a lead-grey colour. Even when the material consists of a coarser or finer granular aggregate the cleavages are prominent and betray the identity of the mineral. The softness (H. = $2^1/_2$) and heaviness (specific gravity 7·5) are also characters of importance.

Before the blowpipe, the constituents of galena may very readily be detected and the mineral so identified. The powder heated on charcoal with sodium carbonate gives the hepatic reaction, proving the presence of sulphur; and at the same time metallic lead is liberated as a bright and malleable bead, while around the assay a yellow sublimate of lead oxide is formed on the charcoal.

When subjected to the action of weathering agents, galena passes into carbonate of lead (cerussite), and where veins of galena crop out at the earth's surface they are usually wholly converted into cerussite. The crystal of galena represented in fig. 11, plate 16, is thinly encrusted on the surface with secondary cerussite. When other solutions are present in the surface waters, the alteration of galena may give rise to anglesite, phosgenite, pyromorphite and other secondary oxygen salts mentioned above. These often occur in cavities in partly decomposed galena, as represented on plate 17: fig. 3 showing cerussite, fig. 9 phosgenite, and figs. 10 and 11 anglesite. Not infrequently during the process of weathering of galena a portion of the sulphur is set free as native sulphur, small crystals of which encrust the cavities of the decomposed ore. Native sulphur formed in this manner is met with in the Victoria mine at Littfeld in Westphalia, and in the lead mines of Derbyshire.

Galena occurs usually in veins, but also sometimes in beds, and is usually accompanied by zinc-blende, copper-pyrites, quartz, chalybite and calcite.

In veins, it is found in the Siegen mining district in Westphalia (from whence come the specimens represented in figs. 1 and 8, plate 16), in the Gonderbach mine at Laasphe, Prussia (figs. 4, 7 and 11), at Neudorf (figs. 5 and 6) and Clausthal in the Harz Mountains, and at several other localities in Germany. Beds of galena are met with in the Muschelkalk (Triassic) strata at Scharley (fig. 3) and Tarnowitz in Silesia, and at Welkenraedt in Belgium. Grains of galena occur disseminated through beds of Triassic sandstone at Mechernich on the northern borders of the Eifel.

Other localities of importance, either for the abundance of lead ore or for the finely crystallized specimens which they yield, are Derbyshire and the North of England, Przibram in Bohemia, Schemnitz in Hungary, Bleiberg in Carinthia, Iglesias in the province of Cagliari in Sardinia, Linares in Spain, and many others. In the United States, the states of Wisconsin, Iowa, Illinois and Missouri are rich in galena. The crystal shown in fig. 2, plate 16, is from Joplin in Missouri, that in fig. 11 from Illinois, and that in fig. 9 from Hazelgreen in Wisconsin. Galena is a widely distributed mineral, and it is not possible to mention more than a few of the numerous localities at which it is found.

Zinckenite may be here briefly described as an example of one of the numerous species of sulphur salts of lead known to mineralogists. It forms radial aggregrates or brushes of acicular crystals which are deeply striated in the direction of their length. The mineral is steel-grey with a metallic lustre. It has in appearance a certain resemblance to stibnite, but it is harder (H. = 3) and heavier (specific gravity 5·3) than this; further it may readily be distinguished from stibnite by the absence of cleavage. Zinckenite is a compound of lead (35 per cent.), antimony (41·7 per cent.) and sulphur (23·3 per cent.). It is found with stibnite and bournonite at Wolfsberg in the Harz, but like the other sulphur salts of lead it is a mineral of only scientific interest.

Cerussite, also known as white lead-ore, is the commonest of the oxygen salts of lead. It crystallizes in the rhombic system, and the crystals are almost always twinned. The upper portion of fig. 4, plate 17, illustrates the form of a simple crystal (the lower portion is in twinned position with respect to this): the large face to the front is one of the two faces of the brachy-pinacoid parallel to which the crystal is tabular; at the sides are narrow faces of the vertical prism, and at the upper end a brachy-dome, pyramid and basal plane. The same forms are shown more clearly in the accompanying text-figure 121: a is the brachy-pinacoid $\infty \breve{P}\infty$, m the vertical prism ∞P, i the brachy-dome $2\breve{P}\infty$, and p the primary pyramid P. In this figure the habit of the crystal is pyramidal, but the tabular habit shown in the plate is more common. The mode of twinning is illustrated in fig. 122, in which the faces are marked with the corresponding letters as in fig. 121. The twin-plane is the unit prism ∞P, and almost invariably the twinning is repeated on two of the faces of this prism; the result being an interpenetration of three crystals in twinned position, which is known as a trilling (fig. 122). Star-shaped groups of twinned crystals with deep re-entrant angles are represented in figs. 1*a* and 1*b*, plate 17. When the crystals are more completely

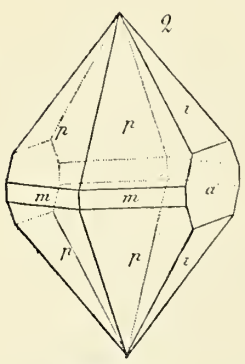

Fig. 121.
Crystal of cerussite.

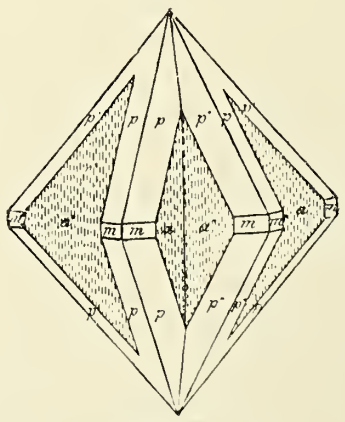

Fig. 122.
Trilling of cerussite.

filled up with material, the resulting form (as may be easily imagined from fig. 122) closely resembles a hexagonal bipyramid somewhat like a crystal of quartz and exactly like the twins of witherite (plate 75) to be described later. When, on the other hand, the individual crystals are thinner and more tabular in habit, the star-shaped forms of the twinned groups are more conspicuous, and when the twinning is repeated many times we have the delicate net-like forms shown in fig. 2, plate 17. This twinning of cerussite is an extremely characteristic feature of the mineral, and often of aid in its identification.

Besides the regular forms just described, cerussite also frequently occurs in fibrous aggregates and brush-like forms, as shown in fig. 3 of plate 17. Granular and compact aggregates are also met with.

The mineral is slightly harder than calcite, and it has a specific gravity of 6·5. It is very brittle, and the delicately crystallized masses such as shown in fig. 2, plate 17, are extremely friable. The clearest crystals are colourless and transparent, with a brilliant adamantine lustre, and a correspondingly high index of refraction ($\mu = 2{\cdot}07$). Often, however, the crystals are white or yellowish and with only a slight degree of transparency; or they may be tinted green or blue (by malachite or chessylite) or black (by earthy galena or limonite).

Being rhombic, crystals of cerussite are optically biaxial; the axial angle is small, and the dispersion of the optic axes is strong. Plates cut from crystals parallel to the basal plane are therefore specially suited for demonstrating the phenomenon of the dispersion of the optic axes. In convergent polarized light the interference-figures resemble those shown in figs. 3 and 4, plate 4, only the hyperbolic brushes are closer together and in white light they are much broader, being coloured red on the convex side and blue on the concave side. The blue band marks the position of the wider angled axes for red light, and the red band marks the narrower angle for blue light.

The mineral is readily dissolved in warm dilute nitric acid with a brisk effervescence, owing to the liberation of carbon dioxide. The lead passes into solution as lead nitrate, and when sufficient cerussite has been dissolved for the solution to become saturated the lead nitrate separates out on cooling as cubic crystals. On charcoal before the blowpipe, the mineral fuses readily and yields a bead of metallic lead and a yellow sublimate around the assay.

Cerussite occurs in the upper portions of veins of lead-ore, where it is a product of the weathering of galena; and it is often found, together with limonite and chessylite, in cavities in quartz. The quartz was originally intergrown with the galena, and being more resisting to weathering agents it has remained behind as the matrix of the cerussite. Sometimes the secondary cerussite is disseminated through the ore and acts as a cementing material of the whole; for example, the grains of the galena-bearing sandstone of Mechernich in the Eifel are so cemented by cerussite.

Some of the finest crystals of cerussite are those from the Friedrichssegen mine between Ems and Braubach in Nassau (figs. 1 and 4, plate 17, and fig. 7, plate 19). Fine crystals are also found at Mies and Przibram in Bohemia, and formerly in the lead mines of the Black Forest in Baden. The fibrous aggregates shown in fig. 3 are from the San Giovanni lead mine in Sardinia, and specimens of the same type were formerly found in the Pentire Glaze mine in Cornwall. Fine specimens have also come from the Altai Mountains and from the neighbourhood of Nerchinsk in Siberia: while large crystallized masses, some of them resembling fig. 2, were abundant at Broken Hill in New South Wales. Many other localities might be mentioned, and all those referred to above under galena may be included.

Phosgenite is a chloro-carbonate of lead with the chemical formula $PbCO_3 . PbCl_2$, thus differing from cerussite in containing chloride in addition to carbonate of lead; but whilst cerussite is a common ore of lead, phosgenite is of quite rare occurrence.

In figs. 5—9 of plate 17 are shown some exceptionally fine specimens of this rare mineral. The crystals are tetragonal, and they differ from the crystals of other tetragonal minerals by usually presenting faces of eight-sided prisms and pyramids. The simplest crystal is that shown in fig. 6, which is bounded by an eight-sided prism with a four-sided tetragonal prism (a small face of which is seen to the front over the fractured portion of the crystal), and the large basal plane. The large crystal shown in fig. 5 is similar, but here the edges between the eight-sided prism and the base are truncated by faces of an eight-sided pyramid. In the crystal represented in fig. 7 the faces of the eight-sided pyramid are large and steeply inclined; above the edge in which the two front faces intersect there is to be seen a face belonging to a four-sided pyramid; and below the same edge is a narrow face of a tetragonal prism truncating an edge of the eight-sided prism, whilst the alternate edges of the latter are truncated by the second tetragonal prism. Finally, in fig. 8, we see an eight-sided prism with a four-sided pyramid, the base, an eight-sided pyramid, and (on the left) a tetragonal prism.

The reflection of light from the crystal in fig. 6 indicates the presence of cleavage cracks parallel to one of the tetragonal prisms; and the horizontal crack in fig. 7 is due to a cleavage parallel to the base. The crystals are soft (H. $= 2^1/_2 - 3$) and heavy (specific gravity 6·3); they are yellowish-white, yellow, brownish or greenish in colour, and possess a brilliant adamantine lustre. The refractive index is 2·1.

The crystals are found in cavities in decomposed galena (fig. 9), and the best specimens, including all of those here figured, are from the Monteponi lead mine near Iglesias in Sardinia. Fine crystals have also been found at Cromford near Matlock in Derbyshire, and near Dundas in Tasmania. Pseudomorphous crystals, altered to cerussite, occur in clay at Tarnowitz in Silesia.

The mineral has been found at but few localities and never in any abundance, so that it is of no importance as an ore of lead, but the fine crystals are treasured possessions in mineral collections.

Anglesite is sulphate of lead, and for this reason it is sometimes rather inappropriately known as lead-vitriol, the term vitriol being more usually applied to hydrated salts of sulphuric acid, such as iron-vitriol and copper-vitriol. The name anglesite is from the island of Anglesey, one of the localities of the mineral.

The crystals are rhombic and are crystallographically similar to crystals of barytes and celestite. The group of simple crystals, irregularly grown together, shown in fig. 12, plate 17, are bounded by only a rhombic prism and the base perpendicular thereto. The crystal in fig. 10 shows a vertical prism in combination with a horizontal prism or dome, whilst those in fig. 11 are bounded by a vertical prism and a pyramid.

When transparent, the crystals display a brilliant adamantine lustre; they may be colourless, yellowish or greenish. The mineral has the same hardness as calcite; and, like all lead minerals, it is very heavy (sp. gr. 6·3).

Anglesite occurs in cavities in galena, to the alteration of which mineral it owes its origin. It is probably not the result of atmospheric weathering and simple oxidation, but has no doubt been formed by the action of acid solutions on the galena.

The finest crystals are from the Monteponi lead mine near Iglesias in Sardinia (from whence come the specimens figured); good crystals have also been found in Derbyshire, at Beresovsk in the Urals, Nerchinsk in Siberia, Phoenixville in Pennsylvania, Broken Hill in New South Wales, and large crystals at Dundas in Tasmania.

Crocoite. The characteristic bright red colour of this mineral is due not to the metal (lead) that it contains, but to the acid radicle; the mineral is a chromate of lead, $PbCrO_4$, and its colour is very similar to that of the well-known artificial salt potassium bichromate. Until a few years ago it was known only as small crystals, at the most a centimetre across, which though well suited for the purposes of crystallographic investigation are not sufficiently prominent to show well in illustrations. The group of large crystals represented in fig. 13, plate 17, show the striated prism faces, and the text-figure 123 shows the same prism faces (*m*) in combination with a steep pyramid (*t*) and a steep ortho-dome (*l*); from this figure it may readily be seen that the symmetry of the mineral is monoclinic.

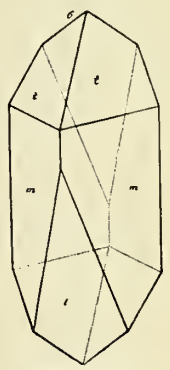

Fig. 123.
Crystal of Crocoite.

The crystals possess about the same hardness as calcite, and their specific gravity is 6. The colour of the powder and of the streak is orange-yellow. The crystals are usually only translucent.

The presence of lead may be readily detected by heating the mineral before the blowpipe on charcoal with sodium carbonate; and the chromium produces an emerald-green colour in a bead of microcosmic salt.

Crocoite has long been known from Beresovsk in the Ural Mountains, where it occurs with quartz and galena in veins of gold ore. It is a product of the alteration of galena, like the other rare lead minerals, such as melanochroite (a basic chromate of lead) with which it is associated. It is also found with gold ores at Congonhas do Campo in Brazil, at Labo on Luzon one of the Philippine Islands, and at Umtali in Rhodesia. The crystals represented in plate 17 are from Dundas in Tasmania, where recently have been found magnificent specimens far surpassing any previously known. The long and slender prismatic crystals from Tasmania are frequently hollow and are terminated by numerous small and brilliant faces.

Wulfenite is a salt of lead with the rarely occurring molybdic acid, being molybdate of lead, $PbMoO_4$.

The crystals are tetragonal and are usually tabular parallel to the base, having the form of quite thin plates with a square outline. The single, fine crystal shown in fig. 12 of plate 18 is set up with the large basal plane to the front; the long narrow faces at the margins are those of a pyramid of the first order, and the small ones on the corners are those of a pyramid of the second order; the diagonal striations on the basal plane are due to oscillation with a very flat pyramid also of the second order. The crystals in fig. 10 are still thinner, while those in fig. 11 are rather thicker and show, in addition to the base, the faces of a square prism.

The small crystals shown on the matrix in fig. 14 are terminated at their upper end by an acute pyramid, whilst below they are terminated by the basal plane; the crystals are thus hemimorphic. Crystals of wulfenite sometimes show a pyramidal-hemihedral development, there being only four alternate faces of the rare eight-sided pyramid on the crystals; this, in addition to the hemimorphic character, indicates that the crystals are really tetartohedral.

As indicated by the name "yellow lead-ore", a common colour of the mineral is yellow (figs. 10 and 11), but, as may be seen from the brilliant red crystals in figs. 12 and 13 and the greyish crystals in fig. 14, this name is not always appropriate. The red colour is probably due to the presence of traces of chromium. Small crystals are often transparent, but larger ones are mostly only translucent; the lustre is adamantine to resinous, and often very brilliant. The hardness is 3, and the specific gravity 6·7—7·0.

Wulfenite occurs as a mineral of secondary origin in deposits of lead ore, and is not very common. The earliest known locality is Bleiberg in Carinthia (figs. 10 and 11); the specimen shown in fig. 14 is from Przibram in Bohemia. The finest crystals are from the Red Cloud mine and other mines in Yuma Co., Arizona; other American localities are in Utah and the Wheatley mine at Phoenixville, Pennsylvania.

Pyromorphite. On account of the different colours which this mineral assumes it is variously known as "variegated lead-ore", "brown lead-ore", or "green lead-ore". The name pyromorphite is derived from the Greek, and refers to the fact that a globule of the mineral formed by fusion is bounded by a number of minute facets, but a name given on these grounds is scarcely an appropriate one.

It may be readily seen from the figures on plate 18 that the mineral is hexagonal; the true symmetry is, however, pyramidal-hemihedral, like that of apatite, though this can only be determined by studying the form and orientation of artificially produced etching figures. The crystals are usually very simple in form, being bounded by only the hexagonal prism and the basal pinacoid, as shown in fig. 3, plate 18. Sharply-developed crystals are somewhat uncommon; the crystals are more usually of a barrel-like shape, being thicker across the middle portion of the prism than at the ends (fig. 1). This is due to a convex curvature of the prism faces; the basal planes are also often somewhat depressed. It is not often that the crystals are scattered singly over the matrix, as represented in figs. 3 and 4; more frequently they are thickly clustered together in groups (figs. 1 and 2). When pyramidal forms are present, they occur as narrow faces truncating the edges between the prism and the base (as shown for mimetite in figs. 7 and 8).

The crystals are at the most only translucent, and they sometimes display a brilliant resinous lustre. In colour they may be yellowish-green, reddish-brown, green, or, less often, a pronounced yellow. The hardness is $3^1/_2$—4 and the specific gravity 7.

The mineral is a chloro-phosphate of lead with the formula $3\,Pb_3(PO_4)_2\,.\,PbCl_2$, corresponding with 15·73 per cent. of phosphous pentoxide, 2·62 per cent. of chlorine, the remainder being lead oxide and lead. Sometimes a small proportion of the phosphoric acid is replaced by arsenic acid, chlorine by fluorine, or lead by calcium, indicating the relation of the mineral to mimetite and to apatite; in fact, with an increase of arsenic acid and a corresponding decrease in the amount of phosphoric acid there may be in a series of specimens a gradual passage from pyromorphite to mimetite.

Pyromorphite has been formed in nature by the action on galena of solutions containing phosphoric acid and chlorine, these constituents having probably been derived from neighbouring deposits of apatite or phosphorite. Conversely, by the action of solutions containing hydrogen sulphide, pyromorphite may be converted back again into galena, and we then have pseudomorphs of galena after pyromorphite: in the specimen shown in fig. 5, plate 18, an alteration of this kind has commenced on the surface of the crystals.

The localities of pyromorphite are often those at which cerussite is found. Fine, large specimens are common from the Friedrichssegen mine, near Ems in Nassau (fig. 1, 2 and 4, plate 18). In the year 1868 a crystallized mass measuring 4 metres in length, 3 metres in height and 1 metre in breadth was taken from this mine. The green crystals shown in fig. 3 are of an old occurrence at Przibram in Bohemia. Zschopau in Saxony, Commern on the northern borders of the Eifel, and Hofsgrund in Baden have also yielded green crystals. Small crystals have been found in the gold-veins at Beresovsk in the Urals, and at Phoenixville in Pennsylvania. Fine, yellow crystals have been found in Cornwall.

Pyromorphite sometimes occurs in sufficient abundance to be mined as an ore of lead.

Mimetite, or mimetesite, is the corresponding arsenic compound to pyromorphite, being chloro-arsenate of lead, $3\,Pb_3(AsO_4)_2\,.\,PbCl_2$. The crystals are hexagonal and are almost always bounded by a hexagonal prism, the basal pinacoid and a pyramid, the faces of the pyramid truncating the edges between the prism and the base (figs. 7—9, plate 18). They may be tabular parallel to the base (fig. 6), or prismatic in habit (figs. 7—9). The colour is usually wax-yellow and the crystals only slightly transparent. The hardness is $3^1/_2$—4, and the specific gravity 7·1—7·3.

The crystals occur singly or in groups attached to the matrix, and they are not common. The best crystals are those from Johanngeorgenstadt in Saxony, from whence came all the specimens represented in plate 18. Other localities are Badenweiler in the Black Forest, Przibram in Bohemia, and Phoenixville in Pennsylvania.

A variety of mimetite, known as *campylite*, contains a considerable amount of phosphoric acid, and forms barrel-shaped or globular crystals or warty aggregates of an orange-red or yellow colour. It was formerly abundant at Dry Gill near Caldbeck in Cumberland.

Mimetite is so rarely met with, and then in only small amounts, that it is of no importance as an ore of lead.

Extraction and Applications of lead. — The ore from which lead is extracted consists largely of galena; cerussite, anglesite and pyromorphite are of quite secondary importance as ores. The galena is first roasted to drive off the sulphur; the roasted product, consisting of lead oxide and lead sulphate, is then smelted with a fresh lot of unaltered galena, when the sulphur and oxygen of the two portions combine to form gaseous sulphur dioxide, leaving the lead behind as metal. The furnace must therefore be so constructed that air may be admitted or excluded at different stages of the process. The metallic lead so obtained contains silver and gold, if these were present in the ore. The purest lead is obtained by an electrolytic process.

Lead has been known from very early times. In the ruins of ancient Troy Schliemann found, amongst other objects, the image of a goddess cast in lead. Its numerous applications depend on its malleability, its chemical resistance to many agents, its easy fusibility (melting point 300° C.), and its heaviness. The poisonous nature of lead, and of its compounds, places, however, certain limitations on its application.

Leaden pipes have been extensively used in olden times, as well as at the present day, for conveying water; and the reason that they can be used for this purpose without any ill effects depends on the fact that substances in the water (carbonic and sulphuric acids) act on the lead and very soon cover and protect it with a thin coating of an insoluble compound, so that there is no further action on the inside of the pipe. In chemical works sheet lead is used for constructing the chambers in which sulphuric acid (oil of vitriol) is manufactured. Porous lead plates coated with lead peroxide are largely used in electrical accumulators. Various alloys of lead have important applications: shot is hardened by the admixture of about $^1/_2$ per cent. of arsenic, and type metal used in printing contains about 20 per cent. of antimony.

Numerous pigments contain lead as an important constituent, and, like all lead compounds, they are poisonous. White-lead is a mixture of various basic carbonates of lead, and is extensively used as an oil paint. Chrome-yellow is lead chromate; and this mixed with Prussian blue gives the so-called green cinnabar. Red-lead is the lead oxide Pb_3O_4; it is a brick-red powder, also known as minium or Paris red, and is much used as a paint and a cement. The yellow lead oxide PbO, litharge or massicot, is used in the glazing of pottery. Lead acetate, or sugar of lead, is used in dyeing and pharmacy.

The strong refrangibility for light possessed by all transparent lead compounds is likewise a characteristic of lead-bearing glass, which is therefore especially suited for the construction of lenses and for imitation gem-stones.

The principal lead-producing countries are the United States of North America, Spain and Germany. The production of the leading countries during the year 1900 is given in the following table. Since the profitable working of lead ores depends largely on the small amounts of silver which are invariably present, the fall in price of silver has caused the stoppage of lead mining operations in certain districts, for instance at Mechernich in the Eifel and in the Upper Harz.

Country.	Tons.	Country.	Tons.
United States	*228500*	*Italy*	*23900*
Spain	*154600*	*France*	*17800*
Germany	*121500*	*Belgium*	*17500*
Mexico	*90500*	*Canada*	*17100*
Australia	*66000*	*Greece*	*16100*
Great Britain	*35000*	*Austria-Hungary*	*13000*

Zinc Ores.

Zinc is not known to occur in nature in the native or metallic state; it is found in combination with sulphur as the simple sulphide, with oxygen as oxide and with acids as oxygen salts. A sulphur salt of zinc is unknown, though zinc is sometimes present in isomorphous mixture in fahlerz. The following are the more important compounds of zinc found as minerals: —

Zinc-blende, ZnS.
Wurtzite, ZnS.
Zincite, ZnO.
Zinc-spinel, $ZnO.Al_2O_3$.
Franklinite, $(Fe,Zn,Mn)O.(Fe,Mn)_2O_3$.
Calamine, $ZnCO_3$.
Hydrozincite, $ZnCO_3.2Zn(OH)_2$.
Willemite, Zn_2SiO_4.
Hemimorphite, $H_2Zn_2SiO_5$.
Adamite, $Zn_3(AsO_4)_2.Zn(OH)_2$.
Hopeite, $Zn_3(PO_4)_2.4H_2O$.
Zinc-vitriol, $ZnSO_4.7H_2O$.

The chemical relation between zinc and some other elements is expressed in the isomorphous replacements which take place in some of these minerals: thus in zinc-blende, wurtzite and calamine some of the zinc may be replaced by iron; manganese, together with or without iron, may be present in zincite, zinc-spinel, franklinite and willemite; and cadmium is sometimes present in zinc-blende and calamine.

The species listed above will be described in turn below in more or less detail, with the exception of adamite, hopeite and zinc-vitriol, these being minerals of lesser importance.

Zinc-blende is also frequently known simply as blende, this being an old mining name of German origin, which, with some qualifying prefix, has been applied to a variety of minerals possessing a more or less metallic lustre combined with a certain degree of transparency. Another name, often applied to the mineral, is sphalerite, this being derived from the Greek and meaning the same as blende.

Crystals of zinc-blende are usually very indistinctly developed, and crystals on which the form can be readily made out are only rarely met with. Their symmetry is tetrahedral-cubic, but sometimes the crystals present quite a holohedral appearance and the hemihedral character is then only to be made out on a critical examination. For instance, the crystals represented in figs. 1 and 2 of plate 20 are apparently combinations of the octahedron and the cube. On the crystal shown in fig. 2 all the faces of the apparent octahedron are equally bright and no difference can be detected between them (the darker face to the right as seen in the picture being in the shade). In the crystal shown in fig. 1, on the other hand, the faces of the apparent octahedron are readily seen to differ in their surface character; one set of faces (a face on the right) are bright and hummocky, whilst those of the other set (one face on the left) are dull and rough; this difference is better shown in fig. 3, plate 19, which gives another view of the same crystal. The same is shown diagrammatically in text-figure 124, where it is manifest that the apparent octahedron is really a combination of two tetrahedra.

Fig. 124.
Crystal of Zinc-blende.
(After G. Tschermak.)

In fig. 3, plate 20, the tetrahedral development is rendered more evident by the difference in size of the faces, those of one tetrahedron being large and those of the other tetrahedron quite small. The edges of the predominating tetrahedron are truncated by narrow faces of the cube, and on the left a twin lamella is plainly to be seen.

The tetrahedral symmetry is also clearly shown in the crystal represented in fig. 4: only one tetrahedron is here present truncating alternate corners of the cube; and the faces of the cube are striated parallel to only one of their diagonals, whereas in a holohedral crystal the striations would be parallel to both diagonals. The two crystals just described are exceptionally perfect for zinc-blende; they are represented again on plate 19 in figs. 4 and 2 respectively.

In addition to crystals with an octahedral or a tetrahedral habit we may also have crystals in which the habit is dodecahedral: the large crystal shown in fig. 1, plate 19, is bounded by faces of the rhombic-dodecahedron alone. In fig. 10, plate 19, the largest faces are those of the rhombic-dodecahedron, and the faces with the outline of an equilateral triangle belong to the tetrahedron; in addition to these there are other faces with the form of isosceles triangles, which belong to the triakis-tetrahedron with the symbol $\frac{3O3}{2}$. On the specimen represented in this figure the transparent, yellowish-brown crystals of zinc-blende are associated with opaque, grey crystals of tetrahedrite, which possess the same degree of symmetry as the zinc-blende.

Twinning is frequent in crystals of zinc-blende, the twin-plane being a face of the tetrahedron, but the appearance of the twinned crystals differs according to their habit. A simple form of twinned crystal is shown in fig, 5, plate 20; the crystal in the lower part of the figure is octahedral in habit and the twin resembles the well-known twins of spinel and magnetite (fig. 9, plate 29). A repetition of the twinning is shown in the crystals in figs. 3, 6, 7 and 8, plate 20. The crystal in fig. 3 (see also fig. 4, plate 19) shows a thin twin lamella parallel to the large tetrahedron face to the left: in fig. 6 two crystals, each bounded by the cube and the tetrahedron, are grown together; and in fig. 7 three individuals are united together in twinned position. The crystal in fig. 8 is octahedral in habit, the two tetrahedra being of equal size, and the corners and edges are truncated by small faces of the cube and the rhombic-dodecahedron respectively;

the narrow dodecahedral face reflecting light at the top of the figure shows a zig-zag course across the three portions of the twin and falls in the same plane on all of them.

The colour of zinc-blende is usually brown to black (figs. 1—9, plate 20), yellowish, brownish-yellow (Fig. 10), red (fig. 12), sometimes oil-green; only exceptionally is the mineral colourless or faintly yellow. Sometimes the crystals are perfectly transparent, and they then exhibit a brilliant adamantine lustre; more often, however, they are translucent to opaque, when the lustre is more metallic in character. The streak is brown to white, depending on the depth of colour of the crystals. Sometimes the crystals are covered with a thin coating of copper-pyrites (fig. 11).

The mineral is brittle and cleaves with great ease in six directions parallel to the faces of the rhombic-dodecahedron. Fig. 9 represents the cleavage form of zinc-blende bounded by the twelve faces of the rhombic-dodecahedron. The hardness is $3^1/_2$—4, and the specific gravity about 4. Many specimens of massive zinc-blende exhibit the phenomenon of phosphorescence; that is, they show sparks or streaks of light when scratched or when two pieces are rubbed together in the dark.

When pure, zinc-blende contains 67 per cent. of zinc and 33 per cent. of sulphur, the chemical formula being ZnS; usually, however, a small proportion of zinc is replaced by a corresponding amount of iron (as FeS), and to this constituent the usual yellow or brown colour of the mineral is due. Small amounts of the rarer elements cadmium, indium and gallium are also sometimes present. Gallium is the only metal besides mercury which may be liquid at the ordinary temperature; it melts at 30° C., but if kept from contact with the solid metal the liquid may be cooled down to the ordinary temperature before it solidifies.

Zinc-blende also frequently occurs in compact and granular masses intermixed with quartz, copper-pyrites and galena. Sometimes it takes the form of botryoidal or reniform aggregates (fig. 13) and it is often difficult to determine whether these belong to the cubic mineral zinc-blende or to the hexagonal mineral wurtzite.

When subjected to weathering, zinc-blende passes into zinc-vitriol. Like galena, zinc-blende occurs in mineral-veins and in beds, and the two minerals are frequently found together. Some of the more noteworthy localities are: in beds at Rammelsberg near Goslar in the Harz, and in veins at Clausthal, Andreasberg, and Neudorf in the Harz. In beds in the Middle Devonian limestone of Brilon in Westphalia; and in veins in the slates of the Rhenish district, for instance, in the Berghäuschen mine near Laasphe (fig. 11). In veins at Freiberg in Saxony, Schlaggenwald in Bohemia (fig. 4), Kapnik (fig. 10) and Schemnitz in Hungary, and Rodna in Transylvania (fig. 5). In beds in the lower Muschelkalk of Beuthen in Prussian Silesia, which here attain the unusual thickness of 12 metres. Beautiful, transparent crystals occur singly in the white saccharoidal dolomite of the Binnenthal in Canton Wallis, Switzerland (figs. 3, 6 and 7); and fine crystals are met with in the lead mine of Bottino near Serravezza in Tuscany, and in the tin mines at St. Agnes in Cornwall. The zinc mines of Derbyshire, the North of England, Wales and the Isle of Man also yield crystals of zinc-blende. Very large, transparent cleavage masses of a pale yellow or yellowish-brown colour are well known from the zinc mines at Picos de Europa in Santander, Spain. The crystal shown in fig. 1 is from Joplin in Missouri, and from the same locality comes the red blende of fig. 12; here the mineral occurs with galena (fig. 2, plate 16) in very large quantities, the production of zinc ore in the state of Missouri amounting to 211,000 tons in the year 1898.

Zinc-blende is smelted for zinc, and the sulphur it contains is sometines saved for the manufacture of sulphuric acid.

Wurtzite has the same chemical composition (ZnS) as zinc-blende, but it crystallizes in the hexagonal system instead of in the cubic. Distinctly developed crystals are, however, of very rare occurrence, and the mineral is usually found as fibrous to compact aggregates. For this reason the two minerals are not always easily distinguished, except by an examination in the polariscope, when it will be seen that zinc-blende is singly refracting and wurtzite doubly refracting. By this means it will be found that the more compact masses consist of a mixture of zinc-blende and wurtzite, while the more coarsely fibrous masses consist of wurtzite alone.

A small specimen of typical wurtzite with a coarsely fibrous and radiated structure, and a brown colour and almost metallic lustre, is represented in fig. 14, plate 20. Material of this kind is found at Przibram in Bohemia, and is sometines known as "Strahlenblende" (radiated blende).

Compact masses consisting of concentric layers of zinc-blende and wurtzite intermixed are known as "Schalenblende" (shelly blende). The concentric shelly structure with alternate bands of lighter and darker material is here (fig. 15, plate 20) very similar to that of malachite and agate. "Schalenblende" occurs in beds of zinc ore in the neighbourhood of Aachen and at Scharley in Prussian Silesia. The specimen represented in fig. 15 shows two bands of galena, and is from the Schmalgraf mine near Aachen.

Wurtzite is used for the same purposes as zinc-blende, but being of less frequent occurrence it is of little importance from a commercial point of view.

Zinc-blende and wurtzite are dimorphous forms of zinc sulphide, and isomorphous with each of them are various other minerals, the more important of which are given in the following isodimorphous group: —

Cubic.	*Hexagonal.*	
Zinc-blende, ZnS.	Wurtzite, ZnS.	Millerite, NiS.
Alabandite, MnS.	Greenockite, CdS.	Niccolite, NiAs.

Zincite, or red zinc-ore, is known to occur only in the neighbourhood of Franklin Furnace and Sterling Hill in New Jersey, U. S. A., but it is there found in considerable quantity. Crystals, which belong to the hexagonal system, are extremely rare, the mineral forming granular and lamellar masses (figs. 1 and 3, plate 21) with a perfect cleavage in one direction. Since pure zinc oxide (ZnO) is colourless, the characteristic red colour of the natural mineral is probably due to the manganese oxide which it invariably contains; the streak is orange-yellow. The hardness is a little over 4, and the specific gravity 5·6. The mineral occurs in association with franklinite and willemite in a crystalline limestone.

Franklinite, an associate of zincite, belongs to the spinel group of minerals, which crystallize in the cubic system, and is closely allied to zinc-spinel and magnetite. Like the other ores of zinc with which it occurs in association, franklinite contains in addition to zinc variable amounts of manganese and iron, and its chemical formula is of the spinel type, namely $(Zn, Fe, Mn)O . (Fe, Mn)_2O_3$. The hardness is about 6, and the specific gravity 5. Crystals are common, and have the form of regular octahedra (figs. 2 and 3, plate 21) with their edges rounded or truncated by the rhombic-dodecahedron. They occur embedded in calcite or in zincite, and are from the district mentioned above for the latter mineral. The common zinc ore at this locality consists of a granular mixture of franklinite, willemite and zincite, with or without calcite.

Zinc-spinel, or gahnite, also belongs, as the name implies, to the spinel group of minerals. Ordinary spinel has the chemical formula $MgO . Al_2O_3$, and in zinc-spinel zinc oxide takes the place of magnesia, so that the formula becomes $ZnO . Al_2O_3$. This

formula corresponds with a theoretical percentage of zinc amounting to 32, but usually this is partly replaced by small, equivalent amounts of iron, magnesium and manganese.

The crystals have the form of the regular octahedron (fig. 4, plate 21), and are sometimes twinned on an octahedral face according to the spinel law (fig. 5). They are greyish-black in colour, and occur embedded in talc-schist at Fahlun in Sweden. In external appearance the crystals closely resemble magnetite, but they may be readily distinguished from this by the fact that they are not magnetic.

As an ore of zinc this mineral is of little importance, but it is of interest from the fact that it is produced artificially in large amounts in the muffles of zinc furnaces. The zinc combines with the alumina of the muffles, and as it cannot be again readily extracted from the compound so formed there is a waste of the material. Further reference will be made to this point when we come to the smelting and applications of zinc.

Calamine is next to zinc-blende the most important ore of zinc, but owing to its inconspicuous appearance it is not a mineral to be readily recognized at sight. Crystals are not common, and are usually quite small and roughly developed; they have the form of rhombohedra, resembling those of chalybite, but are often indistinct and intimately grown together to form crusts. As a rule, however, crystals are not to be seen and the mineral often forms earthy or granular masses, which are usually coloured dark brown by intermixed brown-iron-ore (limonite). Cavities in such masses often present botryoidal, reniform or stalactitic forms on their surfaces (plate 21, fig. 6). When pure, the mineral is white, but more often it is brown or yellowish, or sometimes greenish. The hardness is about 5, and the specific gravity 4·5.

Calamine is a compound of zinc with carbonic acid, that is, carbonate of zinc, $ZnCO_3$; and it is consequently soluble with effervescence in hydrochloric acid. Before the blowpipe on charcoal, the powdered mineral gives a sublimate which is yellow when hot and white when cold. Some calamines contain a small amount of cadmium carbonate, that from Wiesloch in Baden, which is bright yellow in colour, as much as 3 per cent.

The name calamine is often also applied to the hydrous zinc silicate hemimorphite, since these two minerals when in the massive state so closely resemble one another that they cannot be distinguished at sight; and further they frequently occur together under the same conditions. Calamine is usually found in connection with limestone rocks, and owes its origin to chemical processes of a special kind. The weathering of zinc-blende gives rise to sulphate of zinc (zinc-vitriol), a salt readily soluble in water; and when solutions of this salt percolate through the crevices of limestones the zinc is deposited as carbonate and an equivalent amount of calcium is carried away in solution. By such a process — known as a metasomatic process — the limestone may be gradually and completely replaced by calamine. The pseudomorphs of calamine after crystals of calcite mentioned above (p. 50) have been formed in the same manner.

The largest deposits of calamine are those mined at Beuthen in Prussian Silesia, where it occurs as beds in the limestones of the lower Muschelkalk. In the lower levels the ore consists of zinc-blende and "Schalenblende" always in association with marcasite, and forms in the Bleischarley mine beds reaching 12 metres in thickness. Nearer the surface the place of the blende is taken by earthy calamine and hemimorphite; these having clearly been formed by the action of the weathering products of the zinc-blende on the limestones. At the same time the marcasite has been altered to brown-iron-ore (limonite), which being intimately mixed with the calamine imparts to it a brown colour. The production of zinc ores in the mining district of Breslau for the year 1898 amounted

to 522,839 tons, of which 58 per cent. was blende and the remainder calamine and hemimorphite.

Similar deposits occur at Altenberg near Aachen, at Bleiberg and Raibl in Carinthia, Wiesloch in Baden, Iserlohn and Brilon in Westphalia (plate 21, fig. 6), Laurion in Greece, Picos de Europa in Spain, and at several other localities; but never at places where the beds or veins of zinc-blende are unaccompanied by limestones.

Hydrozincite is, like calamine, an alteration product of zinc ores. In addition to the constituents of calamine, it contains some water, being a basic carbonate of zinc with the formula $ZnCO_3 . 2Zn(OH)_2$. It usually takes the form of sinter-like masses (plate 21, fig. 9), or it may have a shelly concentric structure with a stalactitic or botryoidal surface; its colour is white or pale yellowish. It is found in the upper portions of calamine deposits, but is of little importance as an ore of zinc. The best known localities for the mineral are Cumillas and Udlas in the province of Santander in Spain.

Willemite is a silicate of zinc, Zn_2SiO_4, containing 73 per cent. of zinc oxide ($58^1/_2$ per cent. of zinc). Sometimes a portion of the zinc is isomorphously replaced by an equivalent amount of manganese; the variety called troostite from the zinc mines in New Jersey containing 53—68 per cent. of zinc oxide together with 4 to 12 per cent. of manganous oxide.

The original willemite, in which no manganese is present, has the form of very small, yellow to brown, glassy crystals, which with a lens may be seen to be combinations of a hexagonal prism with a rhombohedron. It was found in the now exhausted zinc mine of Altenberg or Vieille Montagne in the neutral territory of Moresnet, between Liège and Aachen.

The troostite variety, which was at first believed to be a distinct mineral species, is found as much larger crystals (plate 21, fig. 7), which are also bounded by a hexagonal prism and a rhombohedron; the edges of these crystals are usually more or less rounded. It also forms granular masses intermixed with zincite and franklinite. Troostite is from the neighbouring localities of Franklin Furnace and Sterling Hill in New Jersey.

Hemimorphite is also a silicate of zinc, but it contains also the elements of water. This water is not water of crystallization, but water of constitution, and it is expelled only when the mineral is heated to a high temperature. The formula $H_2Zn_2SiO_5$ represents an acid salt. When pure, the mineral contains 54 per cent. of zinc.

The mineral often occurs crystallized, but the crystals are small, at the most 1 cm. long and 2—3 mm. thick, and quite unsuited for representing in a picture drawn true to nature. The form of the rhombic crystals is, however, shown in the accompanying text-fig. 125; this is bounded by the brachy-pinacoid *b*, the vertical prism *g*, and at the upper end by the base *c*, and two macro-domes *o* and *p*, while the lower end is formed by the pyramid *s*. The two ends of the crystal are therefore differently developed and the crystal is said to be hemimorphic (compare p. 35). For this reason the name hemimorphite was applied to the mineral.

This hemimorphic development of the crystals is, however, not often very conspicuous, for they usually grow attached to the matrix at their lower end, and then only the base and the dome faces are present. But when such a crystal is subjected to changes of temperature it develops different charges of electricity at its two ends whether crystal faces are present or not. This pyro-electric character, which is peculiar to hemimorphic crystals (those of tourmaline also), may be most conveniently detected in the following manner. A crystal is heated to about 100° C. in an oven and then allowed to cool slowly; during the cooling it is dusted over with a mixture of flowers of sulphur and red lead

through the meshes of a fine sieve; the negative sulphur is attracted to the positively charged lower end of the crystal, and the positive red lead to the negatively charged upper end, and the two ends become respectively yellow and red.

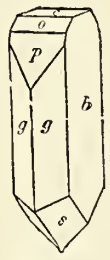

Fig. 125.
Crystal of Hemimorphite

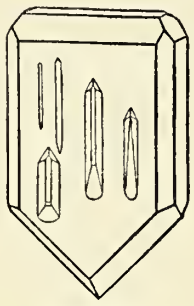

Fig. 126.
Crystal of Hemimorphite with etching figures. (After Tschermak).

The etching figures (fig. 126) produced on the broad pinacoidal face when a crystal is immersed in dilute acid also show the hemimorphism. The shallow pits so produced are only of microscopic dimensions, but they are easily seen to be differently shaped at their two ends. The hemimorphic character of the crystals is thus dependent on the internal structure of the crystalline material, and when crystal faces are present they are merely an external expression of this structure.

Crystals of hemimorphite are usually colourless or faintly yellowish and are transparent with a vitreous lustre. They occur attached by their ends to the walls of crevices and cavities in the massive zinc ore or they are aggregated in brush- or fan-shaped groups forming a crust over the whole surface. When massive, the mineral may be granular, or present a fibrous and shelly concentric structure (plate 21, fig. 8). The massive ore is yellowish, brownish or sometimes green or blue (due to the presence of a little copper). The hardness is about 5, and the specific gravity 3·5. When the powdered mineral is warmed with an acid it is readily decomposed with the separation of gelatinous silica.

Extraction of zinc from its ores. — Zinc melts at 420° C. and volatilizes at 950° C.; it cannot therefore be extracted from the ore as molten metal, and it is consequently obtained by distillation after the manner of flowers of sulphur. The ore must first of all be converted into zinc oxide. This can be readily done when the ore is calamine, for when it is heated the carbon dioxide is expelled leaving zinc oxide. With zinc-blende, however, the operation is more difficult, for this mineral is readily converted by oxidation to zinc vitriol, and this is to be avoided; the ore has here to be roasted in specially constructed ovens and the sulphur converted into sulphur dioxide, which is allowed to escape from high chimneys or is conducted into special chambers for the manufacture of sulphuric acid. The zinc oxide so obtained is mixed with coal and heated in retorts, or muffles, made of fire-clay, when the metallic zinc distills off and is collected in special receptacles. In this process there is a certain amount of loss, for at the high temperature of the furnace the zinc combines with the alumina of the fire-clay and forms zinc-spinel. From this zinc-spinel the metal cannot be profitably extracted and it becomes a waste material, being used for road-metal. It has been estimated that the losses of this kind in the Silesian zinc works amount to 44 to 45 million kilograms of zinc per annum, valued at a third of a million sterling. In order to prevent this waste, it has been proposed to construct the muffles of ignited magnesia or of corundum, but these materials present other drawbacks.

Applications of zinc. — Sheet zinc is used for roofing, for domestic utensils and various ornamental objects. Zinc is also largely used as a coating on iron (the well-known galvanized iron) to preventing rusting: by the action of air and moisture the zinc becomes oxidized, but only on the surface, and the skin so formed prevents any further action. It is also used in the construction of galvanic batteries of various kinds. Brass and the other more important alloys of zinc and copper have already been mentioned.

Compounds of zinc have also various uses. Zinc oxide is used as a paint under the name of white-zinc, but less extensively than white-lead. A white paint known in

the trade as Griffith's white or lithopone is obtained by mixing solutions of zinc sulphate and barium sulphide. Railway sleepers impregnated with zinc chloride are preserved against the ravages of mould. Zinc sulphate is employed in dyeing and in medicine.

Zinc ores frequently contain a small amount of *cadmium*, and since this metal boils at 770° C. it is distilled in the zinc furnaces before the zinc. Alloys containing cadmium are characterized by their low fusibility, one of the best known being Wood's metal (see under bismuth, p. 137). An alloy of 50 % lead, 27·5 % tin and 22·5 % cadmium is especially suited for clichés. Sulphide of cadmium, prepared by precipitation from a solution of a cadmium salt with hydrogen sulphide, is used as an oil or water paint under the name of cadmium-yellow. A pigment used for colouring paper is obtained by precipitating cadmium sulphate with barium sulphide. An alloy of cadmium and mercury is used in dentistry as a filling. The bulk of the cadmium of commerce is obtained from the Silesian zinc ores; in the year 1897 the production amounted to 15,527 kilograms.

The cadmia of the Romans was calamine, which smelted together with copper ore yielded brass. Metallic zinc was probably unknown to them, although articles of brass are frequently found amongst Roman remains.

The *production of zinc* during the year 1900 was as follows: —

West Germany, Belgium and Holland . .	*186,320*	tons.
Silesia	*100,705*	,,
United Kingdom	*29,830*	,,
France and Spain	*30,620*	,,
Austria and Italy	*6,975*	,,
Russia	*5,875*	,,
United States	*110,465*	,,
Total	*470,790*	tons.

This total of 470,790 English tons (of 1016 kilograms) is equivalent to a total of 478,323 metric tons (of 1000 kilograms). In the year 1901 the total production amounted to 500,000 metric tons (= 498,590 English tons), and in 1902 it was increased to 536,760 English tons.

The price of a ton of commercial zinc is about £20, but during the past decade it has been subject to considerable fluctuation; in 1901 it fell to £17, and in 1903 it rose to £24.

Antimony Ores.

Antimony occurs in the native state, but more frequently it is met with in nature in combination with other elements. Most frequently it is combined with sulphur, as stibnite; or with sulphur and a heavy metal (silver, copper or lead), forming the so-called sulpho-salts some of which have already been described above under the names pyrargyrite, bournonite and tetrahedrite. In combination with oxygen it is met with as the two minerals senarmontite and valentinite, which though identical in chemical composition are different in crystalline form. Further, in combination with both sulphur and oxygen we have it in the mineral kermesite. Omitting the antimony compounds previously described, we may then give the following list of antimony minerals: —

Native antimony, Sb.
Stibnite, Sb_2S_3.
Kermesite, Sb_2S_2O.
Senarmontite, Sb_2O_3.
Valentinite, Sb_2O_3.

Native antimony is usually met with as granular or lamellar masses with a metallic lustre and tin-white colour; often, however, it shows a yellowish tarnish and presents no very distinctive appearance. In plate 22, fig. 1, the mineral is associated with calcite, and in fig. 2 is an isolated fragment showing a large cleavage surface. Antimony crystallizes in the rhombohedral division of the hexagonal system, and possesses cleavages parallel to the base and the faces of an obtuse rhombohedron. Naturally occurring crystals are of the greatest rarity, and the crystalline form of the substance has been determined from artificially prepared crystals. These are cube-like rhombohedra with an angle of 87° 7′ between the faces. The closely allied elements, arsenic and bismuth, crystallize in similar forms, the corresponding angle for arsenic being 85° 4′ and for bismuth 87° 40′.

Antimony is brittle and has a hardness of $3^1/_2$. Its specific gravity is 6·7. Heated on charcoal before the blowpipe, it fuses readily and is completely volatilized, yielding a white smoke and a white sublimate of antimony oxide on the charcoal.

Native antimony occurs in the veins of silver ore at Andreasberg in the Harz Mountains and at Sala in Sweden; the two specimens figured on plate 22 are from these localities. It is also found at Allemont in France, Sarawak in Borneo, and a few other places, but it is a rare mineral and is of no importance as an ore of antimony.

Stibnite, also known as antimonite or antimony-glance, is not only the most important ore of antimony but also the earliest known. It was employed by the ancients for darkening the eyebrows, and fragments of it have been found in Spartan graves.

That the mineral contains sulphur was known long ago to Basilius Valentinus; and the presence of this element may readily be demonstrated by simply heating the mineral in the air, when it gives the penetrating odour characteristic of burning sulphur. Heated on charcoal before the blowpipe, stibnite fuses very readily and after a time is completely volatilized, leaving a white deposit of antimony oxide on the surrounding surface of the charcoal. The mineral is soluble in hydrochloric acid with the evolution of hydrogen sulphide, which again proves the presence of sulphur. Chemical analysis shows that stibnite contains 71·4 per cent. of antimony and 28·6 per cent. of sulphur, corresponding with the formula Sb_2S_3.

Stibnite crystallizes in the rhombic system and invariably presents a prismatic habit: the prism is almost square, having an angle of 90° 26′, and two of its edges are usually truncated by the pair of parallel faces of the brachy-pinacoid, while the crystals are often terminated by acute pyramidal faces. As a rule, however, the crystals are small and spear-shaped and frequently aggregated into divergent bunches, so that their form is not readily recognizable. The magnificent crystals from Japan, which first came into European collections about thirty-five years ago, far surpass any crystals previously known. They attain a length of half a metre (20 inches) and a thickness of 5 centimetres, and are moreover extraordinarily rich in faces; thus being not only striking objects in themselves, but also full of interest to the crystallographer. A large and very fine group of these crystals is exhibited in the mineral collection of the British Museum at South Kensington. A single crystal is represented on plate 22, fig. 4, and a group of crystals on plate 23; the forms here shown are the striated vertical prism, the brachy-pinacoid, a pyramid and a brachy-dome.

Not infrequently crystals of stibnite are more or less bent, sometimes in a ziz-zag fashion; the crystal projecting to the left in plate 23 shows a slight bending of this kind.

A very characteristic feature of stibnite is the highly perfect cleavage parallel to the brachy-pinacoid, and very often the brilliant cleavage surfaces exhibit a series of transverse striations (plate 22, fig. 6) due to the bending of the crystals.

Stibnite possesses a metallic lustre, which is especially brilliant on fresh crystals and on cleavage surfaces; on exposure to light this gradually becomes dull. The colour is lead-grey to steel-grey, but often there is a bluish or blackish surface tarnish, as represented in the figures.

The hardness is very low, being about the same as that of gypsum, and it is therefore not surprising that the large crystals from Japan are often somewhat damaged in transport. The specific gravity is 4·5.

The larger masses of stibnite, such as are mined as an ore, consist of radiating or confused aggregates with a fibrous or columnar structure, as represented in plate 22, figs. 5 and 6.

Stibnite is, as a rule, not much affected by weathering, though it does give rise to earthy yellow antimony-ochre, to white valentinite and senarmontite, or occasionally to red kermesite.

Beds of stibnite occur in the rocks of the Culm-measures (Carboniferous system) at Uentrop near Arnsberg (plate 22, figs. 5 and 6) and at Nuttlar near Brilon in Westphalia. In veins it is found at Wolfsberg in the Harz Mountains, often as fine acicular and contorted crystals; with native gold at Goldkronach near Berneck in the Fichtelgebirge in Bavaria; at Bräunsdorf near Freiberg in Saxony; at Felsöbanya and other localities in Hungary; at Kostainik in western Servia; with cinnabar at San Martino and Pereta in Tuscany; and in the neighbourhood of Gedis and Uschak in western Anatolia. The fine Japanese crystals are found in veins in crystalline schists, where they line the walls of cavities; these come from the Ichinokawa mine in the village of Ojoin-mura near Saijo, in the province of Iyo, island of Shikoku. Japan takes a third place in the world's production of antimony, but the greater amount there produced is used for home consumption.

Stibnite, besides being used as an ore of antimony, is also used to a limited extent for the preparation of pure hydrogen sulphide.

Senarmontite, named in honour of the French physicist H. de Senarmont, possesses none of the characters of a metallic mineral, but is colourless, white or grey, and transparent to translucent. Crystals have the form of the regular octahedron, as shown in plate 22, fig. 3; they have a more or less resinous lustre, but are often dull on the surface. The hardness is low (H. = 2), so that the crystals are easily damaged on their edges.

At Sidi-Rgheiss, in the south-western portion of the province of Constantine in Algeria, the mineral is mined as an ore of antimony, and it is here that the best crystals are found. These occur lining cavities in granular masses of senarmontite, which form beds between clay and limestone in the Chalk formation.

Senarmontite is a cubic form of antimony oxide Sb_2O_3, a compound which is dimorphous, since it also occurs in nature as the rhombic mineral *valentinite*. The latter forms small tabular crystals, often grouped in fan-shaped aggregates, with a white or greyish colour and a pearly lustre. It occurs together with stibnite, to the oxidation of which it owes its origin, and is found in small amounts at Bräunsdorf, Wolfsberg and Felsöbanya.

Kermesite, formerly popularly known as red antimony or antimony-blende, is also a mineral of little importance, but it is mentioned here because its chemical composition presents some interest. It may be looked upon as stibnite with one atom of sulphur replaced by an atom of oxygen, the formula being Sb_2S_2O. It forms small tufts or brush-like aggregates of acicular crystals, which are cherry-red in colour with a brilliant lustre. The mineral is found at Bräunsdorf in Saxony, Przibram in Bohemia, and a few other localities.

Applications of antimony. — Metallic antimony is mainly used for making alloys of various kinds. A small amount of antimony increases considerably the hardness of lead; and an alloy of lead with 17 to 20 per cent. of antimony is extensively used for type metal in printing. An alloy containing 10 parts of antimony and 90 parts of tin is the well-known Britannia metal.

Artificially prepared sulphide of antimony, Sb_2S_3 as in stibnite, is used in the manufacture of fireworks; and another sulphide, Sb_2S_5, known as "gold sulphur", finds an application in medicine. The permanent orange-yellow pigment known as Naples yellow is an antimonate of lead; and tartar emetic is an another antimony salt of complex composition.

The countries which produce the largest quantities of antimony are Austria-Hungary, Great Britain and Japan.

Bismuth Ores.

Bismuth is found in nature in the native state, and in combination with sulphur as bismuth-glance, and with oxygen as bismuth-ochre. It is also present in a few other rare minerals, some of which are given in the following list of bismuth minerals: —

Bismuth-glance, Bi_2S_3.	Matildite, $AgBiS_2$.
Guanajuatite, Bi_2Se_3.	Emplectite, $CuBiS_2$.
Tetradymite, Bi_2Te_2S.	Galenobismutite, $PbBiS_2$.
Bismuth-ochre, Bi_2O_3.	Eulytite, $Bi_4Si_3O_{12}$.

Native bismuth may generally be recognized by the reddish tinge of its silver-white colour, but, except on fresh fractures, the surface is often tarnished. Crystals are rhombohedral but very rare, and even when met with they are never more distinct than represented in plate 24, fig. 1. On the other hand, well-formed crystals of bismuth may be readily obtained artificially by fusion; the cube-like rhombohedra (plate 2, fig. 10) have hopper-shaped depressions on their cube faces and they usually display a brilliantly coloured iridescent tarnish. Crystals of native bismuth more frequently present feather-like (plate 24, fig. 2), platy (fig. 3) or net-like aggregates; or the mineral may occur as granular aggregates.

Bismuth fuses very readily, the melting point being as low as 270° C. When heated before the blowpipe, it produces a yellow encrustation on the charcoal. A very characteristic reaction for bismuth, either when in the native state or when in combination with other elements, is given by heating the powdered mineral on charcoal with a mixture of sulphur and potassium iodide; a brilliant red sublimate is thereby produced on the charcoal.

Bismuth possesses a low degree of hardness (H. = 2—3); it is sectile though not malleable, and heavy (sp. gr. = 9·8). It is one of the few substances which contract when fused and expand on consolidation, behaving on this respect like ice and water.

Native bismuth occurs in mineral-veins together with smaltite and niccolite, or sometimes with silver ores, and it is usually associated with barytes and quartz; under these conditions it is found at Schneeberg (plate 24, figs. 2 and 3), Annaberg and Johann-georgenstadt in Saxony. In association with cassiterite it is known from Altenberg and Grauppen (fig. 1) in the Erzgebirge between Saxony and Bohemia; in veins penetrating

granite at Wittichen in the Black Forest; and in veins with cobalt and nickel ores at Bieber in Hesse. Other localities are known in Cornwall, Bolivia and Australia.

Bismuth-glance, or bismuthinite, has a striking resemblance to stibnite, but is somewhat lighter in colour, being light lead-grey to tin-white, and often showing a yellowish tarnish on the surface. Crystals are orthorhombic with a prismatic habit, but they are small and imperfectly developed, and are usually aggregated to form divergent tufts. They possess a perfect cleavage parallel to the brachy-pinacoid and the cleavage surfaces are transversely striated just as in stibnite.

As a rule, these two minerals can only be distinguished by chemical tests. When heated on charcoal before the blowpipe, bismuth-glance gives a yellow encrustation whilst stibnite gives a white encrustation on the charcoal. Still more characteristic, as mentioned above, is the red sublimate given by bismuth in the presence of sulphur and potassium iodide.

When pure, bismuth-glance contains 81·2 per cent. of bismuth. Its hardness is 2, and specific gravity 6·5. It readily alters to bismuth-ochre; the alteration of the grey, metallic bismuth-glance to yellow, earthy bismuth-ochre is depicted in plate 24, fig. 4.

It is found at Schneeberg in Saxony, and at Rezbanya and Moravicza in Hungary. Crystals were formerly found in the Fowey Consols mine and in the East Pool mine in Cornwall. It is abundant at Huaina Potosi, Tasna, and Chorolque in Bolivia; the specimen represented in plate 24, fig. 4, is from the last named locality and represents the bismuth-glance surrounded by secondary bismuth-ochre and accompanied with iron-pyrites, quartz and tin ore. Bismuth-ores were first known from Bolivia some thirty-five years ago, and now this is the principal bismuth-producing country.

Applications of bismuth. — Metallic bismuth is extracted mainly from bismuth-glance; a certain amount being obtained from bismuth-ochre and still less from native bismuth. The production is mainly in the hands of one firm at Giessen in Germany, who make no returns as to the amount produced; by a secret process they are able to extract every trace of impurity from the fused bismuth.

Alloys of bismuth with other metals are characterized by their low melting points, much lower than that of pure bismuth and often below the boiling point of water. Rose's metal, consisting of two parts of bismuth with one of lead and one of tin, fuses at 94°; and an alloy of five parts of bismuth, three of lead and two of tin fuses at $91^1/_2{}^0$; such alloys are used for making clichés. By the addition of cadmium the melting point may be lowered still further; Wood's metal, consisting of 50% bismuth, 25% lead, $12^1/_2\%$ antimony and $12^1/_2\%$ cadmium, melts at $60^1/_2{}^0$; Lippowitz metal is similar in composition.

Basic nitrate of bismuth is used as a white paint, and also very extensively in medicine. The refractive index of glass is increased by the addition of bismuth.

Arsenic Ores.

Arsenic is widely distributed amongst minerals. It occurs in the native state, and in simple combination with sulphur, iron, nickel or cobalt; with sulphur and a heavy metal (silver, copper or lead) in the sulpho-salts, the more important of which we have already mentioned (proustite, and tennantite). It is also found in simple combination with oxygen forming the extremely poisonous arsenic trioxide; and in many oxygen salts.

In this place we shall only describe native arsenic and the two sulphides, realgar and orpiment. Those minerals which contain arsenic in combination with iron, nickel or cobalt will be described further on under the latter metals, for they are more nearly related to the ores of these metals, and in the case of cobalt and nickel, at least, they are far more important for the metals they contain than for the arsenic. On the other hand, the bulk of the arsenic of commerce is obtained from the iron compounds, which will be described under mispickel (FeAsS) and löllingite ($FeAs_2$).

The simple oxygen compound, As_2O_3, is well known under the name white arsenic, but it is of rare occurrence in nature as the dimorphous minerals arsenolite and claudetite. The oxygen salts of arsenic are products of weathering of the iron, nickel and cobalt compounds, and will therefore be described under these metals. In other oxygen salts of arsenic we perceive a close chemical relation between arsenic and phosphorus, as already explained under lead (p. 124), mimetite being a chloro-arsenate of lead and pyromorphite the corresponding phosphate.

Native arsenic occurs as finely granular masses with a mamillated or reniform surface (plate 24, fig. 5) and a concentric structure with shelly separation. On one side of such a broken mass the surfaces will be convex and on the other side concave, while the convex surfaces of one shell fit exactly into the concavities of the shell next to it. The curvature of these surfaces is often more pronounced than in the specimen represented in the figure, and sometimes the form is stalactitic.

The surface of specimens of native arsenic is dark grey to black and dull, but on a freshly fractured surface the colour is tin-white with metallic lustre. In a short time, however, the lustre is lost, owing to surface oxidation.

When heated, arsenic volatilizes without fusion; before the blowpipe on charcoal it forms a white sublimate of arsenious oxide and gives a very characteristic odour resembling that of garlic. The hardness is a little over 3, and the specific gravity 5·7. The mineral is brittle.

It is found, like native bismuth, in mineral-veins together with ores of silver and cobalt. Specially fine masses with mamillated surfaces are found in the veins of silver ore at Andreasberg in the Harz Mountains, in association with galena, dyscrasite, pyrargyrite and calcite. Other localities are Schneeberg, Johanngeorgenstadt, Marienberg and Freiberg in Saxony, Joachimsthal in Bohemia, Zmeov in Siberia, Copiapo in Chile, and Akatani in the province of Echizen in Japan. At the last named locality numerous small rhombohedral crystals are aggregated into globular masses like balls covered with spines.

Metallic arsenic is mainly prepared artificially from the ores of arsenic, and it is used in the manufacture of shot (see under lead, p. 125).

Orpiment is a sulphide of arsenic with the formula As_2S_3. It is one of the minerals known to the ancients, the name orpiment being a corruption of the Latin name auripigmentum used by Pliny, which means "gold paint": the form auripigment is used in German. The name alludes to the characteristic bright lemon-yellow colour and brilliant lustre of the mineral. Another important character is the highly perfect cleavage in one direction, allowing the mineral to be easily split up into thin flexible plates, which are transparent and exhibit a bright pearly lustre on their surface. The mineral is very soft (H. = $1^1/_2$—2). These characters alone always enable the mineral to be readily recognized. When heated, it easily burns with a blue flame giving off fumes of sulphur dioxide and arsenious oxide. Being a transparent sulphur compound, the mineral has been known as "yellow arsenic blende".

Crystals are only rarely met with; they are small and rounded and grown together in crusts, so that it is not possible on inspection alone to make out that they are rhombic with a short prismatic habit. Most frequently, the mineral is found as platy (plate 24, fig. 7) or granular masses. Sometimes, the massive material presents a rounded or botryoidal surface (fig. 6) with a dark colour on the exterior; this form is probably due to the pseudomorphous alteration of native arsenic to orpiment, as is suggested by a comparison of figs. 5 and 6, and comfirmed by the fact that specimens showing all stages of the passage from native arsenic to orpiment have been found at Kapnik in Hungary.

Orpiment frequently occurs in association with the red realgar (plate 24, fig. 7), and in some instances it is possible that it has been derived from this. It is found in a grey sandy clay at Mount Szokolova near Tajova in Hungary, at New-Moldova (fig. 7), in the mineral-veins of Felsöbanya (fig. 6), and at Kapnik, all in Hungary. Also at Allchar near Rozsdan in Macedonia, and Julamerk in Asiatic Turkey. Occasionally it is found in small amount as a volcanic sublimation product, as at Vesuvius and Guadeloupe in the West Indies.

Orpiment is used as a pigment, but most of the material so employed is prepared artificially by fusing arsenious oxide or realgar together with sulphur, or by distillation from a mixture of mispickel and iron-pyrites; the yellow, transparent glassy material so obtained is known as "yellow glass", and as it often contains an excess of arsenious oxide it is very poisonous. The King's yellow used in oil painting is prepared by precipitation in the wet way.

Realgar. While orpiment is characterized by a bright yellow colour, realgar, on the other hand, is distinguished by a bright red colour. On account of its striking colour, the mineral attracted the attention of the ancients, and it was known to the Greeks as *sandarache*, being mentioned by Aristotle under this name. Like orpiment, it is also a sulphide of arsenic, but with the formula As_2S_2. The action of light on the mineral gives rise to a remarkable change, as is often seen in the specimens exhibited in collections; the beautiful red and transparent crystals after a time become transformed to a heap of yellow powder. Oxygen has been absorbed and the compound As_2S_2 has been decomposed into a mixture of powdery yellow orpiment (As_2S_3) and white arsenious oxide (As_2O_3). The presence of the latter in the yellow powder can readily be demonstrated in the following manner: a little of the powder is warmed with a drop of water on a microscope slide and allowed to cool, when it will be seen that colourless regular octahedra of arsenious oxide separate out from the solution. The presence of this free arsenious oxide makes the powder of the decomposed crystals very poisonous, whilst the fresh crystals are not poisonous. When protected from the light, crystals do not undergo any alteration of this kind.

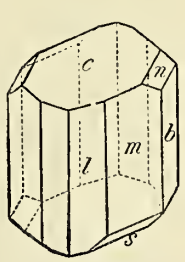

Fig. 127.
Crystal of Realgar.

Crystals of realgar are usually quite small; they belong to the monoclinic system and have a short prismatic habit. The crystal shown in text-fig. 127 is bounded by the two vertical prisms (*l* and *m*), the clino-pinacoid (*b*), the obliquely-placed basal pinacoid (*c*), a clino-dome (*n*), and a pyramid (*s*). Crystals are transparent, while the more frequently occurring granular aggregates are only translucent. The hardness is 1—2, and the specific gravity 3·6.

Good crystals of realgar are found at Nagyag in Transylvania (plate 24, fig. 8); in the white saccharoidal dolomite of the Binnenthal in Switzerland; at Allchar near Rozsdan in Macedonia; and in the Solfatara of Pozzuoli near Naples. Granular masses of realgar often occur intermixed with orpiment as represented in fig. 7.

Like orpiment, much of the realgar used in commerce is prepared artificially; it is a ruby-red, glassy product known as "red glass", and since it usually contains some free arsenious oxide it is very poisonous. When mixed with saltpetre and ignited, it gives an intense white light, this being the "white fire" of pyrotechnic displays. Realgar is also used in cotton printing, in tanning for removing the hair from skins, and in the manufacture of shot.

In addition to the applications mentioned above, these minerals are also used for the manufacture of white arsenic and other preparations of arsenic. The latter are, however, more largely prepared from other arsenical minerals (mispickel, löllingite and niccolite), which will be described further on.

Sulphur.

Sulphur is neither a metal nor on ore, and strictly it does not belong to the group of minerals we are at present considering. Since, however, its principal applications from an economic point of view are mainly identical with those of the two metallic minerals to be next described, it may be most conveniently mentioned in this place.

Not infrequently, native sulphur is referred to as sulphur ore; this is, however, not quite correct, for by ore we understand a mineral from which a metal can be extracted. But, since native sulphur has to be freed from the rocky matrix, in which it occurs embedded, by a process somewhat similar to that employed in extracting a metal from its ore, there exists a certain analogy in the two cases. From this point of view, then, we may consider native sulphur, as well as the minerals (iron-pyrites and marcasite) which are employed for the same purpose, as ores of sulphur. The chemical characters of sulphur are those of a non-metal, and in text-books on mineralogy it is consequently classed with the other naturally-occurring non-metallic elements, namely diamond and graphite.

Native sulphur is often found as magnificent and brilliant crystals with the well-known sulphur-yellow colour. They belong to the rhombic system, and their predominating form is almost always that of an acute rhombic pyramid truncated by the basal plane (plate 25, fig. 2). The two upper pyramid faces to the front of the crystal are inclined to one another at an angle of 106° 38′, and each of these faces is inclined to the base at 108° 21′. Very often the edges between this pyramid and the base are truncated by the faces of an obtuse pyramid (figs. 4 and 5) inclined at an angle of 134° 52′ to the base. Taking the acute pyramid to be the primary pyramid P, the symbol of the obtuse pyramid becomes $^1/_3 P$. The acute sloping edges of the primary pyramid are also often truncated by the faces of the brachy-dome $P\breve{\infty}$; which is to be seen as a narrow face to the left in figs. 3, 4 and 7, while in fig. 6 it is represented as a broad face to the front of the crystal. In addition to the forms mentioned, the brachy-pinacoid $\infty \breve{P} \infty$ is also rarely present, as shown on the left in fig. 4. The ideal development of a sulphur crystal is represented in the accompanying text-fig. 128; here P is the primary pyramid, s the obtuse pyramid $^1/_3 P$, c the base, and n the brachy-dome $P\breve{\infty}$.

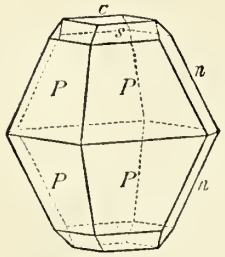

Fig. 128.
Crystal of Sulphur.

When quite pure, native sulphur shows the characteristic sulphur-yellow colour, but this colour may be somewhat masked by the presence of impurities: the varying

colours of the crystals in fig. 1, 4 and 7 are due to the presence of enclosures of asphaltum, while the brown colour of the massive sulphur represented in fig. 11 is due to the admixture of only 0·2 per cent. of a bituminous substance. The colour of earthy sulphur is yellowish-white. Crystals are transparent to translucent, but they are opaque to the Röntgen rays. The index of refraction is high, being 2·0, and corresponding to this the material possesses a brilliant resinous lustre. The faces of crystals are frequently very bright and smooth.

A fractured surface of sulphur is conchoidal and resinous. The material is not wetted by contact with water, neither is it dissolved. It is very soft (H. = 2) and is not at all heavy (sp. gr. = 2·07). When sulphur is held in the warm hand it emits a crackling noise and becomes fissured, so that crystals must be handled with care. When rubbed it becomes negatively electrified. Sulphur burns with a small blue flame, combining with the oxygen of the air to form sulphur dioxide; this gas, as is well known, has a most penetrating odour and bleaches organic colouring matters. In the neighbourhood of furnaces in which sulphurous ores are roasted, the vegetation is all destroyed, as may be seen in the Harz Mountains; and for this reason the chimneys from such furnaces are built high so that the noxious fumes may escape into the upper strata of the atmosphere. The property that the gas possesses of destroying the low forms of vegetable and animal life is extensively made use of in the simple operation of fumigating with sulphur.

Sulphur is readily soluble in carbon disulphide, and as the solution evaporates crystals with the same form as native sulphur are deposited.

Sulphur usually melts at 114° C., but sometimes not until 120° is reached. This peculiar behaviour is due to the fact that at a temperature of 96° the rhombic sulphur may become converted into another modification the melting point of which is 120°. When this alteration takes place the high melting point is reached, and when there is no such alteration the melting point is lower. Molten sulphur, when allowed to consolidate by cooling, does not crystallize in the pyramidal rhombic form characteristic of native sulphur, but in the form of acicular and spear-shaped crystals with a dark amber-yellow colour and belonging to the monoclinic system.

Sulphur is therefore capable of existing in two distinct modifications differing not only in crystalline form but also possessing different physical characters; for example, a different melting point and a different specific gravity, that of rhombic sulphur being 2·07 while that of monoclinic sulphur is only 1·96. This phenonemon was discovered by E. Mitscherlich in the year 1823 and described by him as dimorphism. It is now known, however, that sulphur is not dimorphous, but polymorphous, since it can exist in no less than eight different forms. These are, however, all unstable and pass gradually into the rhombic form, which is the only modification that occurs in nature as a mineral. The acicular crystals of monoclinic sulphur obtained from a fused mass also become changed in the same manner: after a short time cloudy patches of a pale yellow colour appear in the amber-yellow crystals and these gradually spread until the whole crystal becomes converted into a confused aggregate of minute rhombic crystals, when we have a pseudomorph of rhombic sulphur after monoclinic sulphur.

When molten sulphur is heated at a temperature somewhat above the melting point, it gradually becomes darker yellow and viscous; and when poured into water in this condition, it forms a tough plastic mass known as amorphous sulphur. This after an interval of time becomes brittle and paler in colour, owing to its gradual passage into the rhombic modification.

Sulphur volatilizes even at the ordinary temperature, though only in minute traces; a piece of bright silver shut up in a box with sulphur will be blackened by the

silver sulphide formed on its surface. The quantity of sulphur volatilized increases with the temperature, and at the boiling point, 450° C., it gives a brownish-red vapour. As this vapour cools, the sulphur is deposited as a fine, mealy powder, known as "flowers of sulphur". During the process of subliming sulphur, air must, of course, be excluded, otherwise the sulphur would burn.

In nature, sulphur is deposited by the interaction of sulphurous gases emitted by volcanoes. It is also deposited by the waters of some springs, owing to the sulphur compounds they contain being decomposed by contact with the oxygen of the air: in this case, the deposit is earthy with a sinter-like appearance or is stalactitic in form, and is known as mealy sulphur. Small crystals of sulphur are sometimes formed by the weathering of galena: and it is also possible that some of the extensive deposits of sulphur may have been formed by the decomposition of some other mineral, such as gypsum (hydrated sulphate of calcium). That sulphur may be deposited from solution is rendered evident by the specimen represented in plate 19, fig. 5, where a crystal of sulphur is deposited on the end of a stalactite of calcite. It is also worthy of note that free sulphur is present in the substance of some algae.

The preceding remarks on the genesis of native sulphur will help us to realize under what conditions the mineral occurs. Small amounts are found in volcanic materials, in the deposits of sulphur springs, in mineral-veins and in beds of lignite and coal. The most important deposits, however, occur with gypsum (plate 25, fig. 10) and limestone in sedimentary rocks of Tertiary age, where sulphur is often accompanied with crystals of celestite (plate 78, fig. 3), aragonite, calcite, and a few other minerals.

In Europe, the most extensive deposits of sulphur are those of Sicily, in the neighbourhood of Girgenti, Racalmuto (also written Roccalmuto), and Caltanissetta. Here the massive sulphur occurs in beds of limestone, marl, gypsum and clay; and the fine crystals (plate 25, figs. 2, 5, 6, 8, 9) are found in crevices which cross the beds obliquely, or in irregular cavities. Fine crystals, often coated over with or enclosing asphaltum, are also found in the sulphur mines at Perticara in Romagna, Italy. Sublimed sulphur is met with at the Solfatara of Pozzuoli near Naples, on Etna, and in the crater of the Island of Vulcano in the Lipari Islands.

Deposits of sulphur, similar to those of Sicily, are mined at Conil, near Cadiz in Spain: here also the mineral occurs in Tertiary limestone and marl and is accompanied by gypsum, calcite and celestite. At Teruel, in Aragon, sulphur is the petrifying material of fresh-water shells, innumerable shells of *Planorbis* and *Paludina* being filled with this mineral.

In Germany, sulphur is of only sparing occurrence. It is found in gypsum at Weenzen, south-east of Lauenstein in Hannover (plate 25, fig. 10); as minute crystals in the veins of lead ore in the Siegen district of Westphalia (p. 119); and here and there in beds of lignite.

Nodules of pale brownish, massive sulphur are found in a marly shale of Tertiary age at Radoboj in Croatia (fig. 11); and beds of earthy and massive sulphur are found in Caucasia, namely in the Trusso valley to the west of the military road, and in eastern Daghestan.

As a deposit from hot springs, earthy sulphur is met with in Iceland, in the geysers of the Yellowstone Park in the United States, and in Napa Valley in Sonoma county, California. Extensive deposits of sulphur are also known in the states of Utah and Louisiana.

Extraction and Applications of Sulphur. — In the year 1898 there were no less than 720 sulphur mines in Sicily. The native sulphur is separated from the rock by

fusion; the source of heat employed is that given by the sulphur itself, this being a cheaper fuel than coal at the mines. The crude sulphur so obtained is generally further purified by distillation, and this product ("flowers of sulphur") is then fused and cast into sticks to give the well-known roll-sulphur. During recent years the production of Sicilian sulphur has been on the increase: in 1900 the amount exported was 557,668 tons. The larger part of this (162,000 tons in 1900) goes to the United States, where it is used in increasing quantities in the cellulose and paper industries.

Sulphur is used in the manufacture of matches, gunpowder and fireworks, in the vulcanizing of india-rubber, and in the preparation of ultramarine. From it is prepared sulphurous acid, which is largely used for disinfecting, bleaching, and in the paper industry. Flowers of sulphur is used in wine making to destroy the *Oidium* fungus. The largest quantities of sulphur are, however, used in the manufacture of sulphuric acid (oil of vitriol) which is an important reagent, not only in chemical laboratories, but also in all the chemical industries. The greater part of the sulphur used for this purpose is now obtained from iron-pyrites and also to a lesser extent from zinc-blende and other sulphides.

Iron-pyrites Group.

The minerals to be now described (and figured on plates 26 and 27) form a kind of connecting link between arsenic and sulphur (plates 24 and 25) on the one hand, and the iron ores (plates 28—30) on the other. These minerals include iron-pyrites, marcasite, mispickel, löllingite and pyrrhotite, and consist of iron in combination with arsenic or sulphur or of both of these together. They are not used as ores of iron, but of arsenic and sulphur.

Iron-pyrites and marcasite are identical in chemical composition, being disulphide of iron, FeS_2; this compound is therefore dimorphous, crystallizing in a cubic modification as iron-pyrites, and in a rhombic modification as marcasite. Closely allied to marcasite both in chemical composition and in crystalline form are the rhombic minerals mispickel and löllingite; in the former one atom of sulphur is replaced by arsenic, and in the latter both sulphur atoms are so replaced.

Pyrrhotite, which is also included in the present group, often contains, in addition to iron, a small amount of nickel, and it thus forms a connecting link with the nickel and cobalt ores to be described further on. The latter crystallize in cubic and rhombic forms like iron-pyrites and marcasite and are also chemically related to them. The whole series of related minerals thus forms an isodimorphous group as indicated in the following lists: —

Cubic.	Rhombic.
Iron-pyrites, FeS_2.	Marcasite, FeS_2.
Hauerite, MnS_2.	Löllingite, $FeAs_2$.
Gersdorffite, NiAsS.	Mispickel, FeAsS.
Cobaltite, CoAsS.	Glaucodote, CoAsS.
Smaltite, $CoAs_2$.	Safflorite, $CoAs_2$.
Chloanthite, $NiAs_2$.	Rammelsbergite, $NiAs_2$.

The close relation existing between the minerals listed in each of these columns is illustrated by the fact that the chemical compounds that they represent are capable of mixing together to form one and the same crystal; in other words, the minerals are isomorphous. As a result of this, some of them are not known in an ideally pure condition:

for instance, smaltite always contains some iron and nickel isomorphously replacing the cobalt, and chloanthite always contains some iron and cobalt.

The cobalt and nickel ores, with the exception of the rare safflorite and rammelsbergite, are described further on (plates 35 and 36); and the description of the iron compounds to be now given will be followed by that of the iron ores proper.

Iron-pyrites. The name pyrites was used by the Greeks for a stone which gave sparks of fire when struck. No doubt several different minerals were included under this term, while in more recent times the name has often been used as a generic one (e. g. copper-pyrites, arsenical pyrites, etc.). The mineral to be now described is also often referred to as simply pyrites or pyrite, but to avoid any confusion the name iron-pyrites is here adopted.

The mineral contains iron (46·6 %) and sulphur (53·4 %) in the atomic ratio of 1:2, the formula being FeS_2. When heated out of contact with the air, one half of the sulphur is driven off; and when heated in the air, the mineral burns with a small bluish flame like that of sulphur. The sulphur is thereby converted into sulphur dioxide; and if the mineral be roasted for some time the whole of the sulphur will be expelled, while the iron combines with oxygen to form red iron oxide, or in the presence of silica to form iron silicate. In the manufacture of sulphuric acid from iron-pyrites, the mineral is roasted in a current of air and the sulphur dioxide so formed is afterwards converted into sulphuric acid.

Iron-pyrites frequently contains traces of gold, which is set free when the mineral is weathered (p. 75). Traces of the rare metal thallium are also sometimes present; it collects in the dust in the flues of the sulphuric acid plant. Silver, copper, manganese, cobalt, nickel and arsenic also occur as traces in iron-pyrites, but the mineral never contains large amounts of these elements in isomorphous mixture.

Crystals of iron-pyrites belong to the cubic system, and they almost invariably clearly exhibit a parallel-hemihedral symmetry (p. 27), which is indeed so characteristic of this mineral that it is often referred to as pyritohedral hemihedrism. The faces of the cube are almost always striated parallel to only one of their edges, as shown in plate 26, fig. 1, though sometimes these faces may be quite smooth and free from striations (fig. 3). This striation is due to an oscillation between the faces of the cube and the pentagonal-dodecahedron, narrow strips of first one and then the other being alternately developed, although the latter may not always be developed as a definite face upon the crystals. The faces of the octahedron may also show by their striations the hemihedral symmetry (plate 26, fig. 2); the striations in this case being produced by an oscillation between the octahedron and the pentagonal-dodecahedron. In fig. 3, however, neither the cube nor the octahedron faces are striated, and the crystal shows no indications of the hemihedrism, being simply a combination of the cube and the octahedron. The most characteristic form of crystals of iron-pyrites is the pentagonal-dodecahedron (text-fig. 129), which form on this account is often called the pyritohedron. This is shown by the crystals in plate 26, figs. 5 and 6, though on the latter small faces of the octahedron are also present: the faces may be smooth, drusy, or striated either parallel (fig. 7) or perpendicular (fig. 5) to the cubic edge of the form. Another simple form is the dyakis-dodecahedron (text-fig. 130), though this is rare except in combination: in plate 26, fig. 4, it shows in addition small faces of the octahedron, and in fig. 7 we have a combination of the pentagonal-dodecahedron $\frac{\infty O 2}{2}$ and the dyakis-dodecahedron $\frac{3 O \frac{3}{2}}{2}$. Fig. 9 (and text-fig. 133) shows the two last forms together with the octahedron, the faces of the dyakis-dodecahedron being here quite narrow. In fig. 10 the cube predominates and is

combined with the dyakis-dodecahedron and the pentagonal-dodecahedron; the same combination, with the omission of the narrow faces of the last form, being shown in text-fig. 131. Finally, in the pseudomorphous crystal represented in fig. 8 (text-fig. 132) we have a combination of the cube and the pentagonal-dodecahedron.

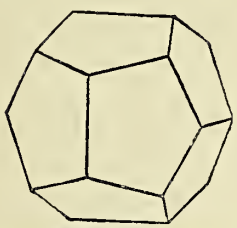

Fig. 129.
Pentagonal-dodecahedron.

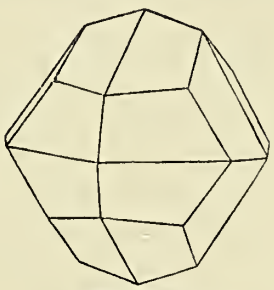

Fig. 130.
Dyakis-dodecahedron.

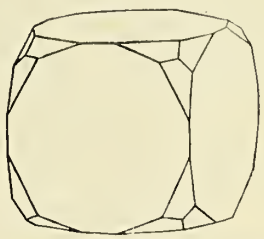

Fig. 131.
Cube with dyakis-dodecahedron.

Twinned crystals of iron-pyrites usually consist of an interpenetration of two pentagonal-dodecahedra (fig. 11 und text-fig. 134), the cubic axes of the two individuals being parallel; and one individual may be brought into the position of the other by a rotation of 90° about any one of these three axes. The cubic edges therefore intercross at right angles, and when these edges are truncated by faces of the cube they show a cross, as in the altered crystal represented in fig. 12. For this reason these twins of iron-pyrites are known as "iron-cross" twins.

Peculiarities in the form of growth of iron-pyrites are not very frequently met with; instances of this have been mentioned on p. 40 (plate 2, figs. 2—4). Here we may

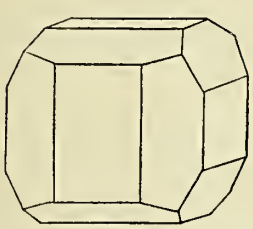

Fig. 132.
Cube with pentagonal-dodecahedron.

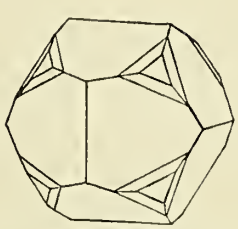

Fig. 133.
Pentagonal-dodecahedron with octahedron and dyakis-dodecahedron.

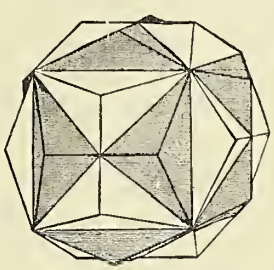

Fig. 134.
Interpenetration-twin of iron-pyrites.

draw attention to the thin discs with radial structure (plate 26, fig. 15) which have recently been found between the laminae of a black shale at Sparta in Illinois, where they are popularly known as "pyrites suns". Not infrequently, numerous smaller or larger crystals of iron-pyrites are aggregated to form balls or irregular nodular masses.

The colour of iron-pyrites is a pale brass-yellow with a metallic lustre; and the powder or streak is greenish- or brownish-black. The brownish-yellow or reddish colour shown by the crystals in plate 26, figs. 8, 12 and 14, and plate 3, figs. 7 and 8, is due to the alteration of the iron-pyrites to iron hydroxide or oxide. Iron-pyrites is very susceptible to an alteration of this kind, and pseudomorphs of limonite ($2Fe_2O_3 . 3H_2O$) or of goethite ($Fe_2O_3 . H_2O$) are by no means uncommon. Still more frequent is the alteration of iron-pyrites to iron-vitriol and sulphuric acid, but in this case the form of the crystals is destroyed. Here there is an absorption of oxygen from the air, just as in the process of burning, and when the alteration proceeds rapidly there may be a

considerable rise in temperature. In this way beds of coal or lignite containing finely disseminated iron-pyrites may become ignited by the oxidation of the latter. The iron-vitriol formed during this weathering of iron-pyrites is soluble in water, and becomes further oxidized to a basic iron sulphate or to iron-ochre; while the free sulphuric acid acts on the surrounding rocks and produces sulphates, such as gypsum, glauber-salt, alum, etc. When limestone or calcite is so attacked, carbonic acid is liberated, and this is carried away by circulating waters and may act on other minerals. In this way the weathering of one mineral gives rise to a series of chemical processes in the earth's crust, whereby other minerals are destroyed and new ones are generated.

The hardness of iron-pyrites is 6. When struck with a steel the mineral gives sparks, owing to the ignition of the sulphur in the detached fragments. On this depended the use of iron-pyrites in the old tinder-boxes and firearms. The specific gravity is 5.

Iron-pyrites is very widely distributed, being one of the commonest of minerals. J. F. Henckel in his "Pyritologia" (1725) speaks of it as 'Jack in every street'. It occurs as small amounts in igneous rocks of almost all kinds, but it is more frequent in sedimentary rocks, especially in clay, clay-slate, limestone and coal; and it sometimes forms the material of fossil shells and fruits. Still more frequently does it occur in mineral-veins and as thick bedded deposits in sedimentary rocks. The iron-pyrites in mineral-veins and in sedimentary rocks must have been deposited from an aqueous solution, probably resulting by the reduction of iron-vitriol. Of the numerous localities at which it is found, we will here only mention those which have yielded specially fine crystals or those at which the mineral occurs in large quantities.

Simple pentagonal-dodecahedra and "iron-cross" twins, either fresh or altered to goethite, are found embedded in the Keuper marl at Vlotho near Minden in Westphalia (plate 26, figs. 12 and 13). Distorted octahedral growths and nodules, the size of a man's head, often intergrown with marcasite, are met with in the Tertiary clay and lignite deposits at Gross-Almerode in Hesse-Nassau (plate 2, figs. 2 and 3); and delicate forms of growth in the clay-slate of Münsterappel near Kreuznach in Rhenish Prussia (plate 2, fig. 4). In the British Isles, the mineral is of common occurrence, and good, crystallized specimens have been found in many of the Cornish mines.

The largest and finest crystals are found at Brosso and Traversella in the Ivrea district of Piedmont and at Rio in the Island of Elba. The mines of iron-pyrites at Brosso have been worked since the time of the Romans; and at the present time 400 to 500 men raise 1000 tons of ore a day. The ore occurs here as lenticular masses, 4 to 40 metres in thickness, with bands of limestone in mica-schist; associated minerals are quartz, dolomite, haematite and various sulphur compounds. The crystals shown in plate 3, figs 6 and 7, are from this locality. At Traversella the magnetite ore (the magnetite shown in plate 29*a*, fig. 1, is from here) occurs at the contact of diorite, and the fine crystals of iron-pyrites (plate 26, figs. 2, 3, 4, 5 and 10) are found in the ore or in the accompanying gangue minerals. On the Island of Elba magnificent crystals of iron-pyrites (plate 26, figs. 6, 7, 9, 11 and 14) occur in association with haematite in the iron mine of Rio, close to the village of Rio Marina on the east coast of the island.

Large deposits of massive iron-pyrites are mined at Rammelsberg, near Goslar in the Harz, where the ore is mixed with copper-pyrites, zinc-blende, galena and barytes (see under copper-pyrites, p. 103). Similar deposits at Meggen in Westphalia have, during the last thirty years, yielded two-thirds of the total amount of iron-pyrites mined in Germany. Of special importance are the enormous deposits of Rio Tinto and other places in the Spanish province of Huelva. The ore here is unusually pure, being mixed with only little quartz and silicates; and as it contains some copper-pyrites it

is at the same time a valuable ore of copper. The content of copper varies from 2·6 to 3·02 per cent., and during the year 1898 the mines yielded 54,000 tons of copper. During the eighties of last century the iron-pyrites mines of Huelva accounted for between one-fifth and one-quarter of the total copper production of the whole world; but since then this has decreased, owing to the increased production from the United States. In the year 1900 the Rio Tinto mines yielded 1,894,500 tons of pyrites, containing on the average 2·744 per cent. of copper; 1,189,701 tons of the ore were smelted in Spain, yielding 21,120 tons of copper, and the remainder was exported to Germany, England and America. Even when poor in copper, the ore is of value for the manufacture of sulphuric acid.

Somewhat similar deposits are also mined at Sulitjelma in Arctic Norway, where the ore consists of a fine-grained mixture of iron-pyrites with copper-pyrites, pyrrhotite and other sulphides, and containing usually a little over two per cent. of copper. During the year 1880 these mines yielded 890 tons of copper; and in 1890, 466 tons of copper were obtained and 60,000 tons of pyrites exported. Another important deposit of cupriferous pyrites, consisting of a mixture of iron-pyrites and copper-pyrites, is met with at Röros in the district of South Trondhjem, in Norway. The total export of pyrites from Norway amounts to over 100,000 tons per annum. The Norwegian ore contains 44—45% of sulphur and $^1/_4$ to 5% of copper, and it possesses the great advantage of being practically free from arsenic.

Of other localities for iron-pyrites, we may mention those represented by specimens figured on the plates: Tavistock in Devonshire (plate 26, fig. 1, and probably also plate 3, fig. 8); Beresovsk in the Urals (plate 3, fig. 9), where the mineral occurs in the veins of gold ore; the French Creek mines in Pennsylvania (plate 2, fig. 1); Pelican Point, Lake Utah (plate 26, fig. 8); and the coal mines at Sparta in Illinois (plate 26, fig. 15).

Uses of iron-pyrites. — Next to native sulphur, iron-pyrites is the most important material for the manufacture of sulphuric acid (oil of vitriol), and for this purpose it is being used in increasingly larger amounts. It is heated in specially constructed ovens in a current of air, and when ignition has been started the material burns by itself: the sulphur dioxide is conducted to the acid chambers, and the red iron oxide which remains behind is utilized as a colouring material or as an ore of iron. Sulphuric acid prepared from iron-pyrites usually contains some arsenic, whilst that prepared from native sulphur is free from this disadvantage.

Iron-pyrites, owing to its high degree of hardness, takes a good polish, and it is used to a certain extent in cheap jewellery, especially in France; the form of cutting adopted is often that of a flat rosette. Polished plates of iron-pyrites have been found in the graves of the ancient Incas of Peru; these are known as Inca-stones, and were probably used as mirrors.

Marcasite has the same chemical composition as iron-pyrites, but it crystallizes in the rhombic system, the compound FeS_2 being dimorphous. Whilst the crystals of iron-pyrites are often large and distinctly developed, those of marcasite, on the other hand, are usually quite small and their form generally obscured by twinning. According to the forms of aggregation assumed by the twinned crystals, various popular names are applied to the mineral; for instance, the aggregate may be spear-shaped, as in the variety called "spear-pyrites" (plate 27, figs. 1 and 2). Simple (i. e. untwinned) crystals are rare and are similar to those of mispickel (text-fig. 136); they are bounded by an obtuse brachy-dome *r*, the faces of which are deeply striated parallel to the brachy-axis, and the vertical prism *M* with an angle of 75° between its faces; often the faces of the prism are quite small, or they may be completely absent. The crystal shown in plate 27,

fig. 1, consists of a twin of two such simple individuals, the twin-plane being a face of the vertical prism; the differently directed striations on the brachy-dome faces of the two portions of the twin meet in the vertical line, which is the trace of the twin-plane and the junction between the two individuals. The re-entrant angles at the sides of the compound crystal are the result of parallel grouping.

A similar kind of twin grouping is shown in the "spear-pyrites" in fig. 2, but here the twinning is frequently repeated, as shown by the fact that the re-entrant angles at the sides are connected with a change in the direction of the striations. This repeated twinning is shown more clearly in text-fig. 135. Sometimes there is a regular intergrowth of these marcasite twins with crystals of iron-pyrites, so that on the same specimen we have together the two modifications of iron disulphide. The small square outlines seen in the lower part of fig. 1 are cubes of iron-pyrites.

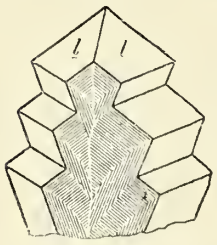

Fig. 135.
Twinned crystal of Marcasite (variety "Spear-pyrites").

Another form of aggregation of marcasite crystals is that of a flattened plate with re-entrant angles along the edge, and bearing a close resemblance to a cock's comb; hence the name "cockscomb pyrites" for this variety. This is due to a repeated twinning on alternate faces of the prism, the prism planes forming the re-entrant angles, and the sides of the plate being a flat rounded brachy-dome. The crystals forming the group represented in fig. 3 show an approach to this form.

Globular (plate 27, fig. 4) and nodular aggregates with an internal radially fibrous structure are of common occurrence in marcasite. The form of the crystals is here obscured, and it is very difficult, or often impossible, to distinguish with certainty whether the material is marcasite or iron-pyrites.

The pale brass-yellow colour of marcasite is very similar to that of iron-pyrites, though perhaps it has a slightly more pronounced tinge of greenish-grey. The colour is, however, often masked by surface tarnish or alteration. The specific gravity of 4·8 is slightly less than that of iron-pyrites, whilst the hardness of the two minerals is about the same (H. = 6). The blowpipe reactions of marcasite are exactly the same as those of iron-pyrites, but as shown by careful researches there are certain differences in the chemical behaviour of the two substances. On some difference of this kind, no doubt, depends the greater readiness with which marcasite weathers to iron-vitriol. It has been suggested, however, that the greater surface presented by the thin and deeply striated marcasite crystals with their numerous re-entrant angles may favour atmospheric weathering to a greater extent than the more limited surface of crystals of iron-pyrites.

Marcasite is on the whole of rarer occurrence than iron-pyrites, but it is nevertheless of wide distribution, especially in mineral-veins, in clay and coal, and as a petrifying material. It is found in the mineral-veins of Clausthal in the Harz, of Freiberg in Saxony, and in Cornwall and Derbyshire; in the beds of zinc ore of Prussian Silesia; and in the deposits of lignite at Littmitz in Bohemia (plate 27, fig. 1). It is abundant in the chalk-marl of England and France, particularly between Dover and Folkestone in Kent (figs. 2 and 4).

When occurring in large amounts, marcasite is mined like iron-pyrites for the manufacture of sulphuric acid; and it is also used for making iron-vitriol.

Mispickel, arsenopyrite or arsenical pyrites, crystallizes in the rhombic system, and the crystals are usually bounded by a short vertical prism *M* and an obtuse, deeply striated brachy-dome *r* (text-fig. 136). The faces of the vertical prism ∞P are inclined at an angle of 112° (or 68° over the acute edge), and the obtuse dome $^1/_4 P \infty$ has an

angle 147° over its upper edge. Simple crystals with these forms are represented in plate 27, figs. 5, 6 and 7. Sometimes the crystals present a long prismatic habit and are terminated by an acute brachy-dome.

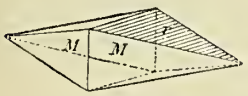

Fig. 136.
Crystal of Mispickel.

Interpenetration-twins of two crystals are of frequent occurrence, the two having a face of the macro-dome $P\infty$ in common (text-fig. 137); very often the two individuals differ in size, the smaller one projecting out of the larger. Twins with the vertical prism as twin-plane, as in marcasite, are also met with, as shown in plate 27, fig. 8; here the spear-like form of the upper portion of the twin is repeated in reversed position in the lower portion, owing to the intercrossing of the individuals over the twin-plane.

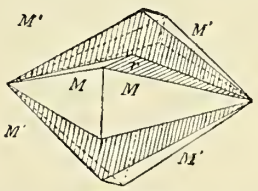

Fig. 137.
Twinned crystal of Mispickel.

Crystals of mispickel are often closely aggregated or confusedly crowded together on the matrix; and columnar and granular aggregates are not uncommon. They possess a metallic lustre with tin-white colour, but are often more or less tarnished on the surface. The hardness is 6, and the specific gravity 6·1.

Not only in the form of the crystals is there a similarity between mispickel and marcasite, but also in the chemical composition. If we replace one of the atoms of sulphur of marcasite (FeS_2) by an atom of arsenic, we get the formula FeAsS of mispickel. Corresponding with this formula, the mineral contains 46 per cent. of arsenic. Small amounts of silver, gold, nickel and cobalt are sometimes present. When heated before the blowpipe, the mineral fuses to a magnetic bead and gives a strong garlic-like odour of arsenic. Heated in a bulb-tube, it first gives a red sublimate of arsenic sulphide and then a black lustrous sublimate of metallic arsenic

Mispickel is principally found in metalliferous veins together with zinc-blende, galena and silver ores, or sometimes with tin-stone. The most important locality is Freiberg in Saxony (plate 27, figs. 5—7), where mispickel occurs in large amount in veins traversing gneiss. Large quantities are also found in many of the tin mines of Cornwall and Devonshire. Other localities are Munzig near Meissen, Marienberg, and Ehrenfriedersdorf in Saxony; Reichenstein in Prussian Silesia, here with löllingite in serpentine; the tin mines of La Villeder in Morbihan, France. Intercrossing twinned crystals (fig. 8) occur embedded in a quartzite in the Deloro mine in Ontario, Canada.

Like the following mineral, löllingite, mispickel is largely used for the preparation of white arsenic and other arsenic compounds. From some of the ores silver and gold are extracted.

Löllingite, or leucopyrite, consists of arsenic and iron with only a small amount of sulphur. The average content of arsenic is 67 per cent. and of sulphur 2 per cent.; and when free from sulphur the formula may be expressed as $FeAs_2$, the two atoms of sulphur of marcasite being here replaced by arsenic. Small amounts of cobalt, nickel, copper, silver or gold are also frequently present. Distinctly developed crystals are rarely met with; these are rhombic with a form similar to that of mispickel; or more frequently they present the form of long needle-like prisms without terminal faces and are embedded in some other mineral, such as serpentine (plate 27, fig. 9). Usually, however, the mineral is met with as granular or columnar aggregates.

The colour is silver-white to steel-grey with a metallic lustre, and in external appearance the mineral has nothing to distinguish it from mispickel. The specific gravity of löllingite (7·4) is, however, considerably higher than that of mispickel (6·1). Before

the blowpipe, the mineral fuses only with difficulty, and the bead obtained is not magnetic; it gives a strong smell of arsenic and only a feeble reaction for sulphur.

A very extensive deposit of löllingite is met with in serpentine at Reichenstein in Prussian Silesia, which, it has been supposed, owes its origin to magmatic separation from the igneous rock from which the serpentine was derived. A similar occurrence, with zinc-blende and garnet is met with at Breitenbrunn in Saxony. The mineral also occurs in the deposits of chalybite on the Erzberg near Lölling in Carinthia; and in the Anniviers valley in Wallis, Switzerland.

Löllingite and mispickel are employed for the preparation of white arsenic (arsenious oxide) and other arsenic compounds. The ore is roasted in a current of air and the white arsenic condensed in long flues. The largest arsenic works are those at Reichenstein in Silesia, which date back to 1699. The annual production of löllingite amounts to 15,000 tons, from which white arsenic, arsenic sulphide (p. 139) and metallic arsenic are obtained, as well as 50—60 kilograms of gold (p. 78).

Pyrrhotite, or magnetic pyrites, is composed of the same elements as iron-pyrites and marcasite, but combined together in the proportion of approximately 1:1 instead of 1:2, the simplest formula being FeS. Usually, however, the mineral contains an excess of sulphur over that required by this simple formula and its actual composition varies from Fe_5S_6 to $Fe_{16}S_{17}$. Of impurities which may be present, nickel is the most frequent, and for this reason the mineral is often an important ore of nickel. In the Norwegian ores the nickel averages 3 per cent., and in the Canadian 5 per cent. The presence of nickel is, however, not essential, and many specimens are entirely free from it, so that the mineral is more appropriately described here than with the ores of nickel.

Crystals are hexagonal and tabular parallel to the basal plane (plate 27, fig. 10). More usually, the mineral is found as granular or lamellar masses (fig. 11). A characteristic feature is the bronze-yellow colour seen on a fresh fracture of the mineral; on the surface this soon tarnishes to a tombac-brown (tombac is a copper alloy, p. 114).

The name magnetic pyrites is applied to this mineral because of its magnetic character: small pieces are attracted by a magnet, and larger pieces will become magnetic with polarity when a magnet has been drawn across them. The hardness is 3—4, and the specific gravity 4·6. The mineral is soluble in hydrochloric acid with the evolution of hydrogen sulphide and the separation of some sulphur. When heated in the air it emits a strong smell of burning sulphur.

When subjected to special alteration processes, the mineral passes into iron-pyrites or marcasite, as proved by the frequent occurrence of pseudomorphs of these after pyrrhotite. By ordinary weathering it forms iron-vitriol.

Pyrrhotite is found in igneous rocks, such as gabbro and basalt, and it was probably formed as a separation from these while they were still in a molten condition. The large deposits occurring in connection with granite probably had a similar origin. It is also sometimes found embedded in crystalline limestone and in metalliferous veins.

In Germany, the largest deposits of pyrrhotite are those on the Silberberg near Bodenmais in the Bavarian Forest (plate 27, fig. 11). The ore here forms lenticular masses interbedded in gneiss at the contact of this with granite, and consists of mixtures in variable proportions of pyrrhotite, iron-pyrites, copper-pyrites, zinc-blende and galena. Tabular crystals aggregated as rosettes are found at Leoben near St. Leonhardt in Carinthia (plate 27, fig. 10); and very similar crystals, altered to iron-pyrites, marcasite or mispickel, have been found in the mineral-veins of Freiberg in Saxony. Deposits, similar to those of Bodenmais, are met with at Sulitjelma in Arctic Norway and at Röros in central Norway; while small crystals occur with native silver at Kongsberg.

Very extensive deposits of nickeliferous pyrrhotite are mined at Sudbury in Ontario, Canada, and from these mines the larger part of the world's supply of nickel is obtained. Here again the ore occurs in connection with a basic igneous rock, from which it has probably separated in the molten condition.

Pyrrhotite is utilized for the manufacture of sulphuric acid, and when it contains nickel it is one of the most important ores of this metal.

Recent investigations have proved the identity of pyrrhotite with the meteoric mineral *troilite*. When fresh, this is bronze-yellow in colour, but it soon tarnishes steel-blue or tombac-brown. The larger nodular masses of troilite readily fall out or are decomposed when the surrounding iron becomes rusted: in this way were formed the rounded empty spaces in the meteoric iron shown in plate 32.

Iron Ores.

The compounds of iron which are useful as ores of the metal are all oxygen compounds, containing, besides iron, either oxygen alone or oxygen and water or carbonic acid. They include the following mineral species: —

Haematite, Fe_2O_3.	Goethite, $Fe_2O_3 . H_2O$.
Magnetite, Fe_3O_4.	Limonite, $2\,Fe_2O_3 . 3\,H_2O$.
Chalybite, $FeCO_3$.	

Several varieties of these minerals are distinguished, and they frequently occur mixed together, so that the ores themselves are often of the nature of rocks rather than of simple minerals. Indeed, such names as iron-stone, red-iron-stone, brown-iron-stone and clay-iron-stone suggest as much. The various impurities which may be present include clay, quartz, coal and iron phosphate.

One of the more important of iron ores, *minette*, is clearly not a mineral species, but a rock, being a highly ferruginous mixture of hydrated iron oxide, calcium carbonate, phosphates, and silica; it has the appearance of pisolitic iron ore (plate 30, fig. 6), but differs from this in the smaller size of its spherical concretions, which are never larger than a millet-seed. Minette occurs as beds in strata of Jurassic age, and its principal development is in Lorraine, Luxemburg and the neighbouring districts in France. The amount of ore available is estimated at 3435 million tons, and most of the iron produced in Germany and France is obtained from this class of ore.

Another iron ore, of much the same composite character and often with an oolitic structure, is known as *chamosite*. This occurs in the Silurian rocks of Bohemia and the Thuringian Forest, and in Bohemia it is of considerable importance as an ore of iron. Since, however, it is more of the nature of a rock than a simple mineral, it need not further engage our attention.

In addition to the simple minerals mentioned above, ilmenite and chromite are also rich in iron; the former will be considered with the compounds of titanium, and the latter will be mentioned in this place with the iron ores. In combination with silica, iron is also an important constituent of many other minerals, but these are of more importance as rock-forming minerals, which we shall consider together in their proper place.

Haematite. When crystallized, this mineral possesses a brilliant metallic lustre and black colour, and for this reason it has long been popularly known as *iron-glance*;

it differs, however, from other minerals to which the term glance is applied in containing no sulphur. On the other hand, the fibrous, compact, and earthy varieties of the mineral possess little lustre and are red in colour. It will therefore be convenient to distinguish the crystallized and massive varieties as iron-glance and red-iron-ore respectively.

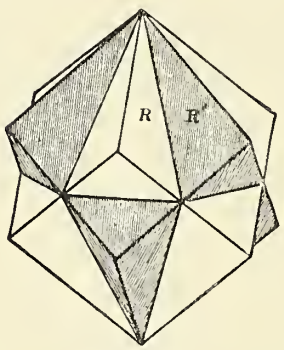

Fig. 138.
Twinned crystal of Haematite.

Crystals of haematite (plate 28) belong to the rhombohedral division of the hexagonal system, and are usually rhombohedral or tabular in habit. The angle between the faces of the primary rhombohedron is 86°, and the faces are often striated parallel to their longer diagonal. The unusually large rhombohedron represented in fig. 1 is of this form, and in addition it carries a narrow face of a more obtuse rhombohedron truncating an edge in the lower part of the figure. At the top of this crystal the edge of a smaller crystal is to be seen projecting from the large rhombohedral face to the left: this is the result of twinning on the basal plane, the two portions having this plane in common but placed in reversed position in respect to it. This twin intergrowth is shown more clearly in text-fig. 138, where the two interpenetrating rhombohedra are of equal size and of ideal development: the shaded rhombohedron R' may be brought into the position of the rhombohedron R by a rotation of 180° about the vertical axis, that is, an axis perpendicular to the basal plane which is here the twin-plane.

In the crystals from Dognacska, shown in fig. 2, the striated primary rhombohedron is also the predominating form, here in combination with the basal plane, which is to be seen as small triangular face. Crystals from the Island of Elba, figs. 3 and 4, show the same rhombohedron, but here with smooth faces, combined with a hexagonal pyramid of the second order $\frac{4}{3}P2$ and a flat rhombohedron; the faces of these forms are lettered r, r' and p respectively in text-fig. 139. The faces of the obtuse rhombohedron r' are often much rounded, as shown in fig. 4.

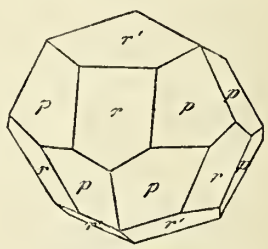

Fig. 139.
Crystal of Haematite.

Crystals of tabular habit, owing to the large development of the basal plane, are characteristic of Alpine occurrences. The crystal shown in fig. 5 is set with up the base to the front, and the bright narrow faces at the edges are those of the primary rhombohedron. Often a number of tabular crystals of this kind are aggregated in not quite parallel position, giving rise to rosette-like groups, known as "iron-roses". An "iron-rose" from St. Gotthard is shown in fig. 7, and one from Ouro Preto, Brazil, in fig. 8. They contain, as a rule, a smaller or larger amount of titanium dioxide, which is often present as mechanically intermixed rutile, but sometimes it is in chemical combination.

Extremely delicate forms of crystallization are sometimes met with in the haematite formed by sublimation on the lava of volcanoes. The temperature of the lava is too low for the mineral to have been formed by direct sublimation, and it has resulted by the interaction of vapours of iron chloride and water. Thin plates of such sublimed haematite from Madeira are shown in fig. 6, and similar specimens are also found at Vesuvius.

The tabular crystals of haematite from the Alps often carry on their surface numerous minute crystals of rutile, with a definite crystallographic orientation between

the two minerals. As shown in text-fig. 140, the prism edges of the crystals of rutile are set perpendicularly to the adjacent edges of the haematite plate, so that over the whole surface of the latter the needles of rutile are arranged in three directions at angles of 60°. On the specimen shown in plate 28, fig. 9 the rutile prisms are much larger than is usually the case, and they follow only one of the three possible directions. This regular intergrowth of two totally distinct minerals is not readily accounted for, since there is neither a crystallographic nor a chemical relation existing between haematite and rutile, the latter being titanium dioxide with a tetragonal form of crystallization. Regular intergrowths of crystals of haematite and magnetite are also met with: here the octahedron faces of the magnetite coincide with the basal plane of the haematite, as shown in the upper left-hand corner of fig. 12, plate 19. These crystals of Alpine haematite sometimes show an alteration of a special kind, their whole substance being replaced more and more by rutile (plate 19, fig. 11 and 12), until at last the crystal with the external form of haematite consists solely of an interlacing network of rutile needles. The latter are arranged in the three directions at 60° explained above, as may be readily seen by the reflections from the surface as the crystal is turned about. In cases of this kind it is not always easy to decide whether we are dealing with an alteration pseudomorph or with an original intergrowth.

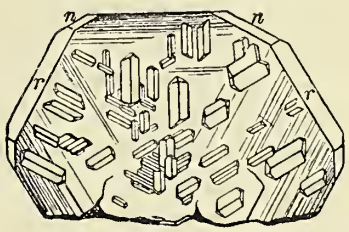

Fig. 140.
Rutile in regular growth on Haematite. (After Tschermak).

When haematite is finely powdered it loses its black or steel-grey colour, and the colour of the powder and of the streak is brownish-red. It is on account of this colour, like that of dried blood, that the mineral receives its name, the meaning of the Greek word haematite being blood-stone. In lamellae of extreme thinness, haematite is transparent with a deep red colour; and the lustre and colour of certain spangled minerals (sun-stone, avanturine quartz, carnallite) is due to the inclusion in them of microscopically small and thin plates of haematite.

When heated, haematite becomes magnetic, while in its unaltered natural state it is only feebly or not at all magnetic. The mineral is slowly dissolved by acids. Its hardness is 6, and its specific gravity 5·3. The pure material contains 70 per cent. of iron.

In addition to distinctly developed crystals, haematite also occurs as crystalline, granular, platy and scaly masses; the last being known as micaceous iron-ore. And when it is found in large quantity it is mined under the name of iron-glance or specular iron-ore. This variety of the mineral is not particularly susceptible to weathering, though when it takes up water into its constitution it passes to limonite.

Fine crystals of haematite are found in the deposits of granular and platy iron-glance on the east coast of the Island of Elba. The iron ores of this locality were known to the ancients, and at the present time the annual production amounts to 200,000 tons. The specimens shown in plate 28, figs. 3 and 4, are from here. Good crystals are also found at Traversella in Piedmont, in Sweden, and in other countries. The rich deposits in Sweden, yielding annually over two million tons of ore, are principally of magnetite, though there is also much iron-glance. Small, thin-tabular crystals are abundant in the deposits of red-iron-ore in Nassau.

Another mode of occurrence of crystals of haematite is in the crevices of silicate rocks. In the Swiss Alps, tabular crystals (plate 28, figs. 5, 7 and 9) are found in crevices in the gneissic rocks, and are associated with rock-crystal, adularia, rutile and several other crystallized minerals. Crystals of rhombohedral habit are met with in the veins

of tin ore at Altenberg in Saxony; and in metalliferous veins at Dognacska in Hungary (fig. 2), Achmatovsk in the Urals (fig. 1), and other places.

Iron-glance of volcanic origin is found at Bertrich in the Eifel, on Vesuvius, Madeira (fig. 6), and elsewhere.

Red-iron-ore, or red haematite, when in a crystalline condition presents an internal radially fibrous structure and a nodular or reniform surface, being then known as kidney-iron-ore. The nodular surfaces of such masses are often smooth and polished, hence the German name "roter Glaskopf", for which there is no English equivalent. The nodular surface of kidney-iron-ore is shown in plate 28, fig. 10, and the fibrous structure on the fractured surfaces in fig. 12. In addition to the radially fibrous structure, there is often also a concentric shelly structure, as represented in fig. 11. Generally, however, red-iron-ore is quite compact and more or less impure owing to the admixture with it of quartz, clay (red clay-iron-stone or "ruddle"), or limestone. The presence of quartz increases the hardness of the ore, while clay diminishes it and the ore is then sometimes quite earthy. All varieties of red-iron-ore possess the red colour characteristic of powdered iron-glance, and in the mining districts where it is worked all the roads and the faces and clothes of the miners are of the same red colour.

Red-iron-ore usually occurs as beds in sedimentary rocks, and sometimes it has replaced limestones. This replacement process has already been described above in connection with a description of pseudomorphs of red-iron-ore after calcite (p. 50). The iron contained in the solutions which gradually replace the limestones may have been brought up from unknown depths in the earth's crust. Large deposits of this kind occur in connection with limestones in Cumberland, Nassau, Westphalia and the Harz. In other cases red-iron-ore may have been deposited directly from solution, or it may have been formed by the dehydration of the precipitates of chalybeate springs.

When occurring in the neighbourhood of igneous rock masses, red-iron-ore is not infrequently altered to magnetite; for instance, at the contact with diabase in the Dillenburg district in Nassau. In such cases the ore must have been deposited at a period prior to the intrusion of the igneous rock.

In Germany, beds of red-iron-ore occur in the Devonian rocks in the district of the Lahn and Dill, and at Elbingerode in the Harz Mountains. The important deposits in west Cumberland and the Ulverston district in north Lancashire fill large, irregularly-shaped cavities in the Carboniferous Limestone. Large deposits of earthy to compact red-iron-ore mixed with limonite and chalybite occur in the Chalk formation at Bilbao on the Bay of Biscay in Spain; the annual production of ore here being five million tons. A similar ore is also mined in north Africa. Brazil is also known to be rich in iron ores, but, owing to the lack of coal for smelting and to the difficulties of transport, they are but little exploited.

The principal use of iron-glance and red-iron-ore is of course as ores of iron. The more compact iron-glance and the finely fibrous red-iron-stone is often cut and engraved for ring-stones, pin-stones and other objects for personal ornament. The material takes a good polish, and is deep black with a brilliant metallic lustre. The finely fibrous material suitable for cutting comes mainly from Cleator Moor in Cumberland, and the compact variety is said to come from India; it is cut, under the name of blood-stone, mostly at Oberstein and Idar in Germany. Engraved cylinder-seals of haematite have been found in the ruins of Babylon and Troy, and in late Roman times the magic Abraxas gems were cut in the same material.

Tools made of polished haematite are used for burnishing gold and silver. Powdered haematite is used as a polishing material, and for making red paint and red pencils.

Magnetite, or magnetic iron-ore, occupies a unique position amongst minerals by reason of its very strong magnetic character. Some specimens of the mineral, especially massive pieces which are somewhat weathered, possess the property of attracting and holding to themselves small pieces of iron (plate 28*a*). In former times these natural magnets or lodestones were set in a suitable mount, and were the strongest magnets known; these are now no longer used, since much stronger and more conveniently shaped magnets can be made artificially by electrical means. Magnetite being a magnetic substance, any fragment of the mineral will be attracted by a magnet, or will affect a freely suspended magnetic needle, but every specimen of the mineral does not possess the power of attracting other magnetic substances; in other words, it is only particular fragments that are magnetic with polarity. It is probable that this polarity is not an original character of the mineral, but that it has been induced in it subsequent to its formation. Such a change may have been brought about by an electric current where magnetite exposed at the surface has been struck by lightning. Crystals found embedded in the solid rock are never magnetic with polarity. When heated to a high temperature (575° C.) natural magnets, like artificial magnets, lose their magnetism.

Crystals of magnetite belong to the cubic system; their forms are illustrated in plates 29 and 29*a*. Fig. 1 of plate 29 shows a regular octahedron embedded in chlorite-schist, and fig. 2 of plate 29*a* shows crystals of the same form grown on the surface of mica-schist; an octahedron detached from the surface of the matrix is shown in plate 29, fig. 5. Octahedra of magnetite are frequently distorted in form, owing to the unequal size of the faces; in fig. 3, plate 29, alternate faces are smaller in size, and the crystal has the appearance of a combination of two tetrahedra. In fig. 4 the crystal is greatly elongated in the direction of one pair of parallel edges of the octahedron, so that it presents the appearance of a rhombic prism terminated by a brachy-dome. In these cases, however, the angle between the faces is the same (109° 28′) as in a regularly developed octahedron. The edges of the octahedron are sometimes truncated by faces of the rhombic-dodecahedron (plate 29, figs. 2 and 6; plate 29*a*, fig. 1), but it is only rarely that faces of the cube are also present (fig. 7). Other crystals of magnetite are bounded by the rhombic-dodecahedron alone (fig. 8), or by this in combination with small faces of the octahedron; in the latter case the faces of the rhombic-dodecahedron are usually striated parallel to their longer diagonal (text-fig. 141).

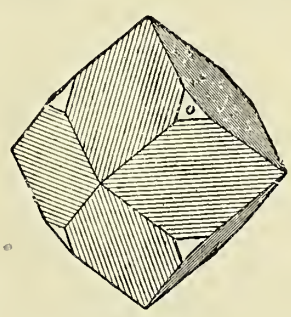

Fig. 141.
Crystal of Magnetite.

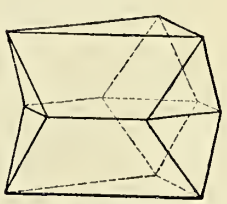

Fig. 142.
"Spinel-twin" of Magnetite.

The twinned crystal shown in plate 29, fig. 9, and text-fig. 142 is an octahedron twinned on an octahedron plane, and resembles the well-known twins of spinel (p. 45). These "spinel-twins" of magnetite usually occur embedded in chlorite-schist.

Delicate forms of growth are often assumed by magnetite, but only when the mineral is embedded in the solid rock; these are therefore only to be observed under the microscope in thin slices of the rock. Such a dendritic growth is shown under a magnification of ninety diameters in plate 59, fig. 1; here, numbers of tiny octahedra are arranged along branches at angles of 90°, parallel to the three cubic axes (as, on a much larger scale, in the specimen of native silver shown in plate 6, fig. 7).

Magnetite is opaque and black, and sometimes exhibits a brilliant metallic lustre (as in plate 29*a*, fig. 2); often, however, the crystals are dull (plate 29, figs. 1, 3 and 4). The streak and powder are of the same black colour. The hardness is 6, and the specific gravity 5.

When pure, magnetite contains 72·4 per cent. of iron, and its formula is Fe_3O_4 or $FeO \cdot Fe_2O_3$. Titanium, chromium, manganese, magnesium, etc. are sometimes present. In its chemical formula, as well as in its crystalline form, magnetite shows a close relationship to the spinel group (see spinel). When subjected to weathering, magnetite passes into limonite or into haematite. When altered to haematite, the crystals are known as martite, this name having been given to a supposed cubic form of iron sesqui-oxide (Fe_2O_3), which is now recognized as haematite pseudomorphous after magnetite. Magnetite undergoes no alteration when heated to redness, but other iron ores when ignited pass into the more stable form of magnetite.

In addition to embedded and attached crystals, magnetite also occurs as granular and compact masses, which are often of very considerable extent. The mode of occurrence of such masses in the earth's crust varies according to their mode of origin. The mineral is of wide distribution as a constituent of igneous rocks (plate 59, fig. 1) and volcanic ashes: and it may be extracted from the powdered rock by means of a magnetized knife-blade. In such cases it usually occurs in only a finely divided condition and is present in greater quantity in the darker coloured rocks; but at times it has separated or accumulated in the igneous rock to form enormous masses, and even mountains are sometimes formed of almost pure magnetite. Rich deposits of this kind are met with and mined in the mountains of Vyssokaya Gora near Nizhni-Tagilsk and the Goroblagodot near Kushva in the Urals, the Kirunavara and the Luossavara and other mountains in Swedish province of Norrbotten, and the Taberg near Jönköping in Småland, Sweden. The richness in iron ore of Russia and Sweden is mainly accounted for by these magnetite deposits. The largest Scandinavian deposit of iron ore is that of Kirunavara and Luossavara in the north of Sweden, where between the surface and a depth of only a metre $1^3/_4$ million tons could be obtained, whilst the total amount of ore available is estimated at 750 million tons. The ore contains on a average 63 per cent. of iron together with about 2 per cent. of phosphorus.

Other deposits of magnetite have been formed by the heating action (contact metamorphism) of igneous rock masses on other ores of iron (chalybite, haematite or limonite), whereby these have been wholly or partially converted into magnetite. Thus, near Siegen in Westphalia a vein of chalybite in contact with basalt has been altered into earthy magnetite, and at Dillenburg in Nassau red-iron-ore has been converted by a diabase intrusion into hard, compact magnetite. These small occurrences in Germany illustrate the mode of formation of the rich deposits of magnetite at Gellivara in Swedish Lapland, and perhaps also those of Dannemora near Upsala and the beds of magnetite interlaminated in crystalline schists at Grängesberg in Sweden. The deposits at Arendal in southern Norway are well known to mineralogists because of the beautifully crystallized silicates (idocrase, epidote, augite, scapolite, garnet, etc.) which they have yielded. Similar, but poorer, deposits of magnetite are met with at Schmiedeberg in the Riesengebirge, at Dognacska in Hungary, and at Traversella in Piedmont.

Fine crystals have been found at several localities, for example: at Traversella in Piedmont, in cavities in the massive ore, in which the crystals of iron-pyrites already mentioned are also found, (plate 29, fig. 6 and plate 29*a*, fig. 1); in the Tyrolese Alps, embedded in chlorite-schist (plate 29, figs. 1 and 9, from the Pfitschthal): in the Binnenthal in Wallis, Switzerland, attached to the walls of crevices in gneiss and

mica-schist (plate 29, fig. 5, and plate 29*a*, fig. 2); in the Stura valley, north-west of Turin (fig. 7); at Nordmark in Sweden (fig. 8). The remaining crystals represented on plate 29 are from Mineville (figs. 2 and 4) and Moriah (fig. 3) in Essex Co., New York.

Magnetite finds an extensive application as one of the most important ores of iron. Suitable pieces are also used as natural magnets.

Chromite, or chromic iron-ore, is a mineral closely resembling granular magnetite in general appearance, but it may be distinguished from this by its brownish-black colour, brown streak and slightly greasy lustre. A ready and certain test for distinguishing these two minerals is by fusing fragments of them in borax beads: in both cases the bead is yellow while still hot, but when cold it is yellowish-green for chromite. This characteristic green coloration is due to chromium, which is an essential constituent of chromite. In a pure condition the mineral consists of 68 per cent. of chromic oxide and 32 per cent. of ferrous oxide, corresponding with the formula $FeO . Cr_2O_3$. Often, however, the ferrous oxide is partly replaced by an equivalent amount of magnesia, and the chromic oxide by ferric oxide and alumina. Chromite is practically unattacked by acids. Its hardness is $5^1/_2$, and its specific gravity 4·8. The rarely occurring crystals are cubic, like those of the closely allied minerals magnetite and spinel.

Chromite occurs as granular masses, and has been formed as a separation from molten igneous rocks rich in olivine, thus having an origin similar to that of some magnetite deposits. These olivine rocks are particularly susceptible to weathering, and it is in the serpentines derived from them that deposits of chromite are usually met with.

Rich deposits of chromite occur in Asia Minor, and it is from here that the bulk of the world's production of this mineral is now obtained. The mines are situated in two districts: one is near the south-west coast of Anatolia not far from the island of Rhodes; and the other, in the north, at Chatalja-Dagh and Chardi to the south and south-west of Mount Olympus. The annual production of one of the richest mines amounts to 10,000 to 12,000 tons of the best ore, valued at about £50,000.

Considerable deposits are also found in North Carolina, between Ashe County and Clay County; the yield here in 1896 was 17,887 tons. In Russia, chromite is found only in the Urals, and in the government Perm there were, in the year 1893, twenty-five mines which produced 14,600 tons of ore; but since that date the production has fallen off. Chromite has been mined also at Kraubat in Upper Styria, at Hestmandö in Norway, and in some other localities.

Chromite is used for the preparation of chromium compounds, such as potassium chromate and bichromate, chromic acid and various chrome colours; and, more recently, metallic chromium has been extracted from it, this being added to steel to give the hard chromium-steel. Owing to the high melting point of chromium, it is only recently that the extraction of this metal has been possible on a commercial scale. The method now extensively in use was discovered by H. Goldschmidt and depends on the very high temperature produced by the burning of metallic aluminium. Chromium oxide is mixed with aluminium powder, and this surrounded by another mixture of aluminium powder and barium peroxide in which a magnesium ribbon is laid. The magnesium is ignited and this ignites the aluminium, which in the outer layer burns at the expense of the barium peroxide and so produces an extremely intense heat; at this high temperature the aluminium in the interior is oxidized at the expense of the chromic oxide, whereby alumina (corundum) and metallic chromium are produced.

Besides occurring as an essential constituent of chromite, chromium also occurs in crocoite (p. 123), in some garnets, and in a few other minerals; but none of these are used for the extraction of the metal or its compounds.

Chalybite, or spathic iron-ore. Whilst magnetite, the iron ore which we have just considered, owes its origin to the action of heat, another important ore, namely chalybite, has been deposited from aqueous solution. It is, however, not from solutions at the earth's surface that the mineral can be deposited, since in contact with the air and water it is not stable. Being ferrous carbonate, $FeCO_3$, it is, like all other ferrous salts, readily oxidized, and at the earth's surface it soon becomes altered to the more stable compound limonite. For this reason, where beds or veins of chalybite outcrop at the surface, there is a gossany capping of limonite.

When chemically pure, chalybite contains 62 per cent. of ferrous oxide or 48·2 per cent. of iron; but the iron may be partly replaced isomorphously by equivalent amounts of manganese, magnesium or calcium, whilst the ores are often mechanically intermixed with clay, coal or other impurities. The mineral dissolves with effervescence (owing to the liberation of carbon dioxide) in warm hydrochloric acid, and the solution becomes yellow. When ignited it becomes black and magnetic. The hardness is 4, and the specific gravity 3·9.

Crystals (plate 29, figs. 10, 11, 12) have usually the form of a rhombohedron with angles of 107° between the faces. They are often very like crystals of dolomite in appearance, as may be seen from a comparison of plate 29, fig. 11, and plate 75, fig. 7; the crystals of both these minerals are frequently curved in saddle-shaped forms, and they possess perfect cleavages parallel to the faces of the rhombohedron. Both in crystalline form and chemical composition, chalybite and dolomite are closely related to the rhombohedral minerals calcite, magnesite, rhodochrosite and calamine, all of which are carbonates of chemically allied metals. Some of them exhibit characteristic differences in colour, depending on the metal they contain, which in some cases enables us to distinguish one mineral from another by inspection alone. The colour of fresh and unaltered chalybite is yellowish-grey, but usually it shows a rich brown colour owing to the partial alteration of the mineral. When weathered, the mineral passes into limonite, as shown in the pseudomorph of limonite after chalybite in fig. 12. Manganiferous chalybite becomes bluish-black on weathering, owing to the black colour of the separated manganese oxide; this is known as "blue ore", whilst fresh chalybite is "white ore", and the ordinary ore partially weathered to limonite is called "brown ore".

Chalybite also occurs as coarse or fine grained crystalline aggregates; and this massive material forms the ordinary type of ore. Intimately intermixed with clay it forms nodular masses in some sedimentary rocks, and is then known as clay-iron-stone or clayey sphaerosiderite; or when mixed with carbonaceous matter it is called black-band iron-stone. Pure chalybite also occurs in nodular masses with an internal radially fibrous structure and is then known as sphaerosiderite; in plate 29, fig. 13, this is seen in a cavity in basalt.

Chalybite occurs in veins and is then usually accompanied by quartz and copper-pyrites (plate 11, figs. 5 and 10); as, for example, in the Siegen district in Westphalia, in the Harz, in the mining district of Schmalkalden in the Thuringian Forest, and in Cornwall. Or again, it forms thick beds, one of the richest being that of the Erzberg near Eisenerz in Styria; this has been worked ever since the time of the Romans, and the annual production amounts to about one million tons of ore containing on the average 42 per cent. of iron. Similar deposits are mined at Hüttenberg in Carinthia and at Gyalar in Transylvania. The iron ore occurring as extensive beds in the Lias strata of the Cleveland district in Yorkshire consists mainly of chalybite in a pisolitic form; here about $5^1/_2$ million tons of ore are raised per annum. Of great importance are the clay-iron-stones and the black-band iron-stones found in the Coal-measures of England and

South Wales, and in the coal mining district of Ruhr in Prussian Silesia. Sphaerosiderite is found in basalt at Steinheim near Hanau (plate 29, fig. 13) and at several spots in the Vogelsberg. Localities for good crystals of chalybite are: Neudorf in the Harz (fig. 10); Lintorf in Hannover (fig. 11), these often with small scalenohedral faces; the Siegen district in Westphalia; and several of the Cornish mines.

Chalybite is one of the best ores of iron, and is of great importance for the production of the metal.

Limonite, or brown-iron-ore, is distinguished from the other ores of iron by the fact that it never occurs as crystals; pseudomorphous crystals of limonite after some other mineral are, however, by no means uncommon. Apart from these pseudomorphous crystals, the mineral itself forms fibrous aggregates or compact amorphous masses. The former are often stalactitic (plate 30, fig. 5), tubular (fig. 4), reniform or botryoidal on the exterior; in the interior these rounded forms are brown with a fibrous structure, whilst on the exterior they are often black and shining, hence the German name "brauner Glaskopf", for which there is no English equivalent. Sometimes the internal structure is very similar to that of red-iron-ore, suggesting that in some cases limonite may have been derived from haematite, though of course it is possible that the reverse transformation may also have taken place. Thus, for example, the radially fibrous and concentric shelly structure shown for limonite in plate 30, fig. 3, is very similar to that of red-iron-ore in plate 28, fig. 11. The bulk of the ore in a deposit of limonite usually consists of amorphous and compact or earthy material. Sometimes, a pisolitic structure is apparent throughout the whole mass of ore, which consists of small spherical concretions, with a concentric shelly structure, set in a cement of earthy limonite: this is known as pisolitic iron-ore or as bean-ore (plate 30, fig. 6). When the spherical concretions are much smaller, the structure is described as oolitic, an example of which is the ore known as "minette" (p. 151).

Pure limonite contains 59·9 per cent. of iron, corresponding with the formula $2Fe_2O_3.3H_2O$; but the compact masses of this mineral, as well as pisolitic iron-ore and "minette", are rendered impure by the admixture of clay, silica, calcium carbonate, phosphates, etc. The presence of calcium and manganese in the ore is rather an advantage, since less limestone need be used in the smelting, and less manganese added for making special kinds of steel. The hardness of fibrous limonite is 5—5½, and the streak brown to ochre-yellow: the specific gravity is 4, though often lower than this when impurities are present. When a fragment of the mineral is heated in a bulb-tube, water is expelled and condenses as drops on the side of the tube, and the brown limonite is converted into red iron oxide.

At the earth's surface, limonite is the most stable compound of iron, and it results from the weathering of other iron ores and other minerals rich in iron. In the form of earthy iron-ochre it separates around chalybeate springs, in swampy places on moors and meadows (bog-iron-ore, marsh-ore, meadow-ore), and at the bottom of pools and lakes (lake-ore). The fibrous and more compact masses occur in the gossany capping of lodes and deposits of other minerals (see under chalybite and copper-pyrites). Pisolitic iron-ore occurs as a deposit from springs either directly or as a replacement of limestone.

In Germany, veins and beds of limonite occur in the Siegen district in Westphalia, in Nassau, on the borders of the Vogelsberg, in the Harz, and in the Thuringian Forest; rich deposits are met with at Peine in Hannover, at Salzgitter in the Harz, and in Prussian Silesia. Bean-ore occurs principally in fissures and cavities in limestone, for example in the Swabian Jura, and at Kandern in Baden (plate 30, fig. 6), as also

at Lauben in Switzerland. The localities for "minette" have already been mentioned on p. 151.

Bog-iron-ore is widely distributed over depressed areas in north Germany, in European Russia, and in Finland and Sweden. A typical occurrence in North America is that of the Three Rivers district in province Quebec. Deposits of bog-iron-ore, like those of peat, may be observed in their process of growth, and when such a deposit has been exhausted, it may again be worked after the lapse of some time. Owing to the never failing presence of phosphates in this ore, it was formerly of only little use as an ore of iron; it gave a very fluid metal especially suitable for castings, but these are very brittle ("cold-short"). Now, however, that iron can be readily freed from phosphorus by the Thomas-Gilchrist process, and as the Thomas slags are of value as fertilizers, these ores are of increased importance: and the same applies to "minette", which is the most important of iron ores in Germany.

Besides being used as an ore of iron, limonite in its ochreous variety is employed as a pigment (yellow ochre). The pigment known as umber is a mixture of limonite, manganese oxide and clay. (Cologne umber is an earthy lignite.)

Goethite is a mineral which receives its name from the poet Goethe, who added the study of minerals and rocks to his many-sided interests, and he not only collected minerals and gems but also published several of his observations relating to them. Such a name might very well have been associated with a more beautiful and interesting mineral than the one to be now described. This is a hydrated oxide of iron, containing the same constituents as limonite but combined in different proportions, the formula being $Fe_2O_3 . H_2O$. The pure mineral contains 62·9 per cent. of iron.

Crystals of goethite belong to the rhombic system and are developed in two very different habits. In one, they are long-prismatic or acicular with a form similar to that of manganite (compare plate 34, figs. 5—7), and are usually closely aggregated in bundles (plate 30, fig. 1); this variety is sometimes known as needle-iron-ore. Other crystals have the form of very small and thin scales, which are transparent with a ruby-red colour; this is the variety called pyrrhosiderite. Nodular aggregates of very fine scales (plate 30, fig. 2) have received the name lepidocrocite. The mineral also occurs as compact masses, as in the pseudomorph after iron-pyrites shown in plate 3, fig. 8.

The crystals possess a perfect cleavage in one direction. Their hardness is 5—5½, and their specific gravity 5·3.

Most frequently, goethite occurs in association with limonite, either as strings of lepidocrocite or crystallized in glittering scales in the cavities. Under these conditions it is found in the Siegen district in Westphalia, at Bieber near Giessen in Hesse, and some other places. Amethyst with enclosed needles of goethite is found at Oberstein on the Rhine, on Wolf's Island in Lake Onega, Russia, and in Brazil. The best crystals are from the Restormel iron mines at Lostwithiel and the Botallack mine near St. Just in Cornwall; these are prismatic in habit and have a brilliant lustre. Crystallized material is also found at Florissant in El Paso Co., Colorado (plate 30, fig. 1).

Metallurgy of Iron. — The metallic iron obtained by smelting iron ores in blast-furnaces is not a chemically pure iron, but always contains other elements, principally carbon, in combination: pure iron is not used for technical purposes. The furnace is charged with alternating layers of iron ore and coke, and when necessary some limestone is also added. The latter combines with any silica which may be present in the ore and with the ash of the fuel to form an easily fusible slag. With certain classes of ore, such as the German "minette", which contain the necessary amount of calcium this addition of limestone is not necessary. The lowest layer of coke is ignited and a strong

blast of hot air is forced into the furnace. In this way the upper layers of ore become gradually heated, water and carbon dioxide are expelled (if the ore has not been previously treated in special roasting ovens) and iron oxide is formed. Carbonic oxide, formed by the burning coke, rises in the furnace and gradually reduces the heated iron oxide to a spongy mass of metallic iron rich in carbon. Lower down, where the temperature is greater, this fuses and dissolves more carbon, and owing to its great weight it flows down and collects in the bed of the furnace. From here the metallic product is drawn off from time to time, whilst the lighter slag flows almost uninterruptedly from a higher opening. The slag is utilized for road-metal, or for the manufacture of cement or compressed artificial stone. The process is a continuous one, for fresh materials are constantly being charged into the top of the furnace, and the products continuously drawn out from the bottom.

The raw iron, or pig-iron, so obtained contains about 4 per cent. of carbon, together with small and variable amounts of silicon, phosphorus, sulphur and manganese. Being fusible at a comparatively low temperature, it is used for castings. White cast-iron contains the carbon in chemical combination, and since the presence of manganese favours the formation of carbides, ores rich in manganese are used for smelting; the product, which may contain up to 15 per cent. of manganese, is very brittle and hard, and has a distinctly crystalline structure with large, silver-white surfaces of fracture; it is principally used for the manufacture of steel and wrought iron. Grey cast-iron, on the other hand, contains a portion of the carbon as free graphite; it is less hard and less brittle, has a finely granular structure and grey colour, and is more suited for castings than is white cast-iron.

The brittleness of cast-iron is due to its high content of carbon, and when deprived of a portion of this the iron is less brittle. At the present time the decarbonization of iron is usually effected by the Bessemer process. The molten iron is transferred direct from the blast-furnace to a large pear-shaped vessel, supported on trunnions and known as a converter, and hot air under pressure is blown through the molten mass. By this means the various impurities, carbon, sulphur, silicon and phosphorus, are oxidized and burn off, forming gases and slag, while the phosphoric acid combines with the lining of lime in the converter (thus forming the Thomas-Gilchrist basic slag, which, owing to the calcium phosphate it contains, is of considerable value as a fertilizer). When the amount of carbon has been reduced to about 2 per cent. (as may be determined by a spectroscopic analysis of the flame from the converter) the blast of air is shut off, and the product, now converted into steel, is poured out.

Steel is a variety of iron containing 0·8 to 2·5 per cent. of carbon in chemical combination, which as iron carbide is alloyed with the remainder of the metallic iron. Steel melts at a temperature of 1400° C.; it can be cast, hammered, welded, and hardened; and in rolling-mills it is made into rails, girders, armour-plates, sheets and wire. The use of steel on a large scale for various purposes has been rendered possible only since the introduction of the much more efficient Bessemer process. When steel is raised to a red-heat and quickly cooled it becomes brittle and very hard: hardened steel of good quality is capable of scratching window-glass, or even quartz. When hardened steel is again heated and allowed to cool slowly it becomes softer, or annealed, and the longer and more intense the heating the softer does it become. It is thus possible by these means, together by the addition of other metals (chromium, nickel, tungsten, manganese, titanium), to produce steel of any desired degree of hardness and suited to the varied purposes to which it is put. All these processes naturally add considerably to the cost of production; for instance, the fine quality

of steel used for the escapement pins in the best chronometers is worth many times as much as pig-iron.

Iron containing still less carbon than steel is a malleable iron; and this can also be produced directly from pig-iron by the Bessemer process, or from white cast-iron by the puddling process. This variety of iron is tough and not very hard; it fuses only with difficulty, but softens at a red-heat and can then be shaped by hammering and welded. Its numerous applications are well known, from the simple bars of garden fences to the most intricate hammered iron work with delicate rosettes and tendrils.

Production of Pig-iron in the year 1900.

Country.	Tons.	Percentage of the total.
United States	*14 099 870*	34·4
United Kingdom	*9 052 107*	22·1
Germany	*8 351 742*	20·4
Russia	*2 850 000*	6·9
France	*2 699 424*	6·6
Austria-Hungary	*1 350 000*	3·3
Belgium	*1 018 507*	2·5
Sweden	*520 606*	1·3
Spain	*294 118*	0·7
Other countries	*731 397*	1·8

Appendix to the Iron Ores.

Meteoric Irons and Meteoric Stones.

Iron readily combines with other elements, and especially with oxygen; for this reason metallic iron never takes its origin at the earth's surface, and any pieces which become exposed to weathering are soon rusted and destroyed. Native iron is, in fact, a mineral of the greatest rarity. It is found as large masses, weighing as much as 50,000 pounds, in a basalt at Ovifak on the island of Disko, off the west coast of Greenland. The basalt at this place has been erupted through beds of coal, and it is possible that a reduction of the iron compounds in the basaltic magma has been effected by the coal, in much the same way that iron ores are reduced in a blast-furnace. All other known occurrences of terrestrial iron are of little importance.

On the other hand, masses of metallic iron of greater or less size, occassionally found on the earth's surface, are known to have fallen from outer space. These consist mainly of metallic iron, and are known as meteoric irons; whilst other meteorites, composed largely of stony material (i. e. silicates), are distinguished as meteoric stones. These bodies are quite unattractive in appearance, and the extraordinary interest they possess depends solely on their extra-terrestrial origin and comparative rarity.

The fall of a meteorite to the earth's surface is accompanied by a display of brilliant light and by loud explosions: owing to the great height and velocity of the moving meteor, its advent is often made manifest over a very wide area. When these solid bodies, travelling through space with an enormous velocity, come near enough to our earth to pass through the upper rarified strata of the atmosphere, the friction of the air acts as a check to the velocity and the energy of motion is largely transformed into heat. The air in front of the body becomes suddenly compressed and consequently heated, while the meteor itself is raised to a glowing temperature on the surface. The rapid motion through the air drives the molten particles on the surface to the rear of the moving mass, giving rise to the characteristic valleys and ridges radiating from the back of meteorites (plate 32*a*, fig. 1). Many of the particles will, however, be completely separated from the main mass, and these give rise to the tail of fire of a meteor or shooting star. The velocity of meteors when they reach our atmosphere is several miles per second, being that of the planets and comets, but this velocity rapidly diminishes, and for an instant the meteor appears to stand still and ceases to glow; frequently the mass then breaks up with a loud and far-reaching report, similar to that of a cannon, and with the accompaniment of thunder-claps and rumblings the fragments fall to the ground. The loud and sharp report is usually attributed to the bursting of the meteor, and the subsequent thunder-claps to the rushing of the air into the vacuous space behind the moving mass, while the rumblings are due to the reflection of these sound waves from different strata of the air or from clouds. Since, however, the report is also heard when only a single meteorite reaches the earth, it is held by other authorities that the report is not caused by the bursting of the mass, but by the intense compression of the air in the front of the moving body.

Usually only a single meteorite falls, but sometimes there may be two or three or several, while in a very few instances, for example, at L'Aigle in Normandy in the year 1803, some thousands have been picked up after a fall. On reaching the earth, a meteorite may be hot on the surface, but in the interior it is more often cold, and temperatures as low as —50° C. have been reported. This is not surprising when we remember that the meteorite has only just arrived from the extremely cold regions of outer space, and that during its short and rapid flight through our atmosphere there has not been sufficient time for the heat thereby generated to be conducted into the interior of the mass. The sudden heating may, too, be the cause of the breaking of the mass into fragments, and this would explain the irregular angular form of most meteorites. In some instances the several fragments belonging to the same meteoritic fall may be fitted together and the original mass re-constructed. For example, after the fall at Butsura in India on the 12th of May 1861, there were picked up three stones at distances of 4—5 kilometres apart; these fitted together exactly and showed, with the exception of one corner, the original shape and size of the whole mass. The shallow cup-shaped depressions or "thumb markings" so characteristic of the surface of meteorites are doubtless due to the chipping away of fragments from the heated surface, these being subsequently rounded by the friction of the air and the new surface covered by a skin of fused material. Following this brief description of meteorites in general, we shall now more particularly consider the meteoric irons and then pass on to the meteoric stones.

Meteoric irons, or siderites, are always covered on their natural surfaces by a thin, dark coating of oxide (plate 31, fig. 6), like that to be seen on iron which has been strongly heated. When fresh, this has the character of hammer-slag and the composition of magnetite; when weathered it passes into hydrated oxide of iron. In external form

the masses are irregular with angular edges and corners, and the surfaces are often rounded and marked with shallow concave depressions or pittings.

Internally, the material is crystalline, with a structure corresponding to that of the cubic system; and this may often be recognized on the exterior by the presence of cleavages parallel to the faces of the cube. In order to display more clearly the internal structure, meteoric irons are sawn through, and the section faces polished and etched with dilute nitric acid or bromine water. Most meteoric irons when so treated exhibit on their etched surfaces a system of lines of greater or less fineness intercrossing at different angles, which are known, after their discoverer, as *Widmanstätten figures* (plate 31, figs. 1—4). These consist of long grey bands of *kamacite* surrounded by narrow reddish bands of *taenite* (plate 31, fig. 1), whilst the remaining space is filled up with *plessite*, which may, however, consist mainly of kamacite (plate 31, fig. 2) or of taenite (fig. 1). Some meteoric irons, for example that of Braunau, consist wholly of kamacite, and these do not show the figures just described. That Widmanstätten figures can be developed by etching therefore depends on the fact that the meteoric iron is, as a rule, built up of different constituents which are differently attacked by acids; and further, the regularity of the figures shows that these constituents are arranged together in a perfectly definite manner in the mass. A specially characteristic feature of meteoric iron is the invariable presence of nickel in alloy with the iron; together with 89—95 per cent. of iron there is 4—10 per cent., or rarely as much as 10—15 per cent., of nickel. Other chemical elements present in small amounts are cobalt, sulphur, phosphorus, carbon and chromium. Kamacite and taenite are both alloys of iron and nickel, the former containing less, and the latter more nickel; kamacite isolated from the meteoric iron of La Caille in France contains 91·9 per cent. of iron and 7 per cent. of nickel; while the taenite from the same iron contains 85 per cent. of iron and 15 per cent. of nickel. Taenite is more difficultly attacked by acids than kamacite.

The angle at which the different bands intersect depends on the orientation of the section with respect to the crystalline structure of the mass of the iron. When the section is parallel to a face of the octahedron, the bands will be at 60° (plate 31, fig. 1, and plate 32); when parallel to a face of the cube, at 90° (plate 32, fig. 2); and when the section has neither of these directions, the angles will be different. Since the bands are sections of lamellae, it follows that these lamellae are arranged parallel to the faces of the octahedron, and meteoric irons possessing this structure are known as *octahedral irons*. As may be seen from plate 31, the lamellae are very variable in width; the iron of Carlton (fig. 4) has fine lamellae, those of Descubridora (fig. 2), Staunton (fig. 3) and Toluca (plate 32) have lamellae of medium width, while in some others the width may exceed 2 mm. This arrangement of the lamellae indicates a zonal structure of the iron parallel to the faces of the octahedron, and the lamellae pass uninterruptedly throughout the whole mass, forming a single crystalline individual often of considerable dimensions. Thus the two masses of meteoric iron found at Chupaderos in Mexico, when placed together to form the original mass, measure nearly 5 metres in length, $2^1/_2$ in breadth and $^1/_2$ m. in height; usually, however, the masses are much smaller.

In other meteoric irons the lamellated structure parallel to the octahedron faces is not present and the mass is homogeneous in composition; but these still clearly show the cleavage parallel to the faces of the cube, and they are consequently known as *hexahedral irons* (hexahedron being another name for the cube). Irons of this type are often traversed by twin-lamellae ("Neumann" lines) parallel to the octahedral faces, but they show no Widmanstätten figures when a polished surface is etched. The best example of this type of structure in meteoric iron is afforded by the meteorite which fell at

Braunau in Bohemia. In a third type, the mass consists of smaller or larger irregular fragments of hexahedral iron forming a breccia; this is known as a *brecciated hexahedral iron*. An example of this is seen in the Kendall County meteorite (plate 31, fig. 5), which consists of an aggregate of small grains of iron, with some dark grains of troilite. Another example with much larger grains is the Mount Joy meteoric iron (plate 32*a*, fig. 4) the original mass of which weighed 348 kilograms; here the Neumann lines due to lamellar twinning are to be seen in some of the grains.

The specific gravity of meteoric irons varies between 7·80 and 7·88. Most irons readily acquire permanent magnetism.

Of the chemical constituents of meteoric iron mentioned above, the cobalt is alloyed with the iron and nickel of the kamacite, etc.; and the sulphur is combined with iron to form another constituent, namely *troilite* (FeS, see 151). This is usually present as rounded grains or nodules embedded in the nickel-iron (plate 31, fig. 5), and being liable to weathering they sometimes fall out, leaving rounded spaces (plate 32, fig. 1). In many meteoric irons the troilite takes the form of thin plates arranged parallel to the cube faces, which, on the polished sections, appear as very fine lines (0·1—0·2 mm. in thickness), and are called "*Reichenbach*" lamellae, after their first observer. The phosphorus is present as a phosphide of iron and nickel called *schreibersite*, $(Fe, Ni, Co)_3P$; which forms metallic white laths embedded in the kamacite. The carbon occurs in combination with iron as carbide (Fe_3C, called *cohenite*), and also in the free state as *graphite* or as *diamond*. The presence of diamond has been detected in the meteoric irons of Cañon Diablo in Arizona and Magura in Hungary, and in a few others.

With the exception of troilite, all the meteoric minerals just mentioned are scarcely ever visible to the unaided eye. But in another group of meteoric irons large grains of olivine are plentifully distributed through a network of metallic nickel-iron (plate 31, fig. 7). The earliest known example of this type is the large block weighing 700 kilograms discovered near Krasnojarsk in Siberia by the traveller Pallas, and for this reason known as the Pallas iron; the name *pallasite* being also extended to the whole group. The olivine possesses characters — chemical composition and angles between the crystal faces — identical with those of the olivine of terrestrial rocks, but the crystals of the former are sometimes much richer in faces than those of the latter. In addition to olivine, other silicates (bronzite and plagioclase) are also sometimes present. Meteorites of this group are of comparatively rare occurrence, and they form a connecting link between the two main groups, the meteoric irons and the meteoric stones; and for this reason they are called *mesosiderites* or siderolites.

The **Meteoric stones,** or aerolites, also contain some metallic nickel-iron, but only as grains or particles scattered through the mass of silicates; the latter include olivine, bronzite, augite, plagioclase and glassy matter. In addition, there is often some gas (hydrogen, etc.), and rarely diamond.

Meteoric stones, which have not been broken during their flight through the air, possess certain peculiarities in their external form, which are dependant on their direction when falling. As shown in plate 32*a*, figs. 1—3, the front of the stone, which encountered all the resistance of the air, is rounded, while the back is flatter and puckered. The whole surface is covered with a thin, dark brown or black skin (plate 31, figs. 8 and 9*a*), caused by fusion on the surface during the flight through the air; and the minute characters on the surface of this skin also indicate the direction of flight. Thus in fig. 1 (plate 32*a*) minute furrows and ridges radiate from the apex to the sides of the stone; this being due to the backward flow of molten particles on the surface, which streamed round the sides and collected in ridges and projections on the back

(figs. 2 and 3). The stone here figured (plate 32*a*, figs. 1—3) fell at Guča in Servia on 28 November 1891, and is now at Belgrade.

In their interior, meteoric stones present much the appearance of certain terrestrial rocks which have consolidated from fusion, or of certain compact tuffs, with the addition of the glitter of the metallic particles (plate 31, fig. 9*a*). But, in most cases, they present a certain peculiarity of structure not met with in terrestrial rocks; this consists in the presence of numerous rounded crystalline grains, usually only of microscopic size, called chondrules by G. Rose; this structure being described as chondritic, and the stones exhibiting it as *chrondrites*. The origin of this structure has not been satisfactorily explained; F. Berwerth considers such stones to have been formed by the partial fusing together of a meteoric ash or dust.

A noteworthy feature of freshly-fallen meteoric stones is the absence of any alteration of their material which might be attributed to the presence of water and weathering.

Only exceptionally are meteorites of any considerable size, and even the heaviest irons are of moderate dimensions owing to their high specific gravity. The large mass of meteoric iron found near Melbourne in Australia in 1854, and now to be seen in the Mineral Gallery of the British Museum, weighs about $3^1/_2$ tons (3731 kilograms); that of Bendegó in Brazil, now in the Rio de Janeiro Museum, weighs 5360 kilograms; while a still larger mass, weighing $36^1/_2$ tons, has been transported from Melville Bay in Western Greenland to New York. The largest known mass is that which still remains at Bacubirito in Mexico; it measures about $13 \times 6 \times 5$ feet and has been estimated to weigh 50 tons. These are, however, quite exceptional, and the number of specimens weighing over 50 kilograms (i. e. about 1 cwt.) preserved in meteorite collections is limited to a few dozen. For instance, the Vienna collection in 1902 possessed ten irons exceeding this weight, but only one stone; and in the British Museum there is also only a single stone weighing more than 50 kilograms.

The descriptions of the meteorites given on the sheets accompanying plates 31, 32 and 32*a* require, perhaps, some explanation. The one or more masses belonging to each meteoritic fall are named after the locality where they were observed to fall or were found: thus the Roebourne meteoric iron (plate 31, fig. 1) was found in 1892 at a spot 200 miles to the south-east of Roebourne in the north of Western Australia; the specimen here represented is a slice weighing 444 grams cut from a mass which when found weighed 86·8 kilograms.

Historical. — Being bodies which have descended from the heavens, meteorites have at all times been regarded with reverence and awe; in early times they were thought to have fallen from the stars and to have been sent by the gods. Temples were built for them, and they are represented on numerous Roman and Grecian coins (betyl coins). Thus a stone worshipped in the temple at Emisa as the sun-god Elagabalus, and afterwards taken to Rome by the Emperor Elagabal, a priest of the sun-god, was represented on numerous coins. The Venus of Paphos in Cyprus was described as a rough triangular stone; and the statue of Ceres, the earliest image of Pallas at Athens, and the stone at Delphi were also meteorites. "Iron from heaven" was known to the Egyptians as far back as 4000 B. C.

A stone built into the Kaaba at Mecca has been known before the seventh century; it is said to have fallen red from heaven and turned black through the sins of men. Mohammed at the taking of Mecca did not venture to destroy the stone, but walked around it seven times and kissed it; since then it has been an object of the greatest veneration to all Mohammedans.

Several meteorites have been found in the prehistoric barrows of the Ohiotales in North America; some of them as loose pieces of an olivine-bearing pallasite laid upon an altar (the pallasite shown in plate 31, fig. 7, was found at a distance of only 100 kilometres from these graves); while the so-called ear-plugs made of copper were plated with meteoric iron. In Japan, until recent times, meteorites were regarded as household gods; and in Duruma, East Africa, a stone which fell in the year 1853 was thought by the Wanikas to be sent by god, until at the time of defeat they lost all faith in it and sold it to the missionaries. A stone which recently fell in Sabetmahet in India was bedecked with flowers and sprinkled with sandal-wood powder, and was so carefully guarded that only the smallest fragments could be obtained for scientific investigation. The famous meteoric iron found by Pallas at Krasnojarsk in Siberia had been regarded by the Tartars as a holy relic. And one of the two stones which fell on 10 September 1886 in the neighbourhood of the village of Novo-Urei in the Karasnoslobod district, government Pensa, is said to have been broken up and powdered by the peasants, since they attributed a magic power to this stone from the heavens. This stone is of interest in being the first meteorite in which diamonds were detected.

The meteoric stone which fell at Ensisheim in Elsass in the year 1492 is of particular interest as being the earliest authentic meteorite still preserved; for years it remained suspended by a chain from the roof of the church and it is now kept in the Rathhaus of the town. The following is a translated extract*) from a document preserved in the church: —

"On the 16th of November, 1492, a singular miracle happened: for between 11 and 12 in the forenoon, with a loud crash of thunder and a prolonged noise heard afar off, there fell in the town of Ensisheim a stone weighing 260 pounds. It was seen by a child to strike the ground in a field near the canton called Gisgaud, where it made a hole more than five feet deep. It was taken to the church as being a miraculous object. The noise was heard so distinctly at Lucerne, Villing, and many other places, that in each of them it was thought that some houses had fallen. King Maximilian, who was then at Ensisheim, had the stone carried to the castle: after breaking off two pieces, one for the Duke Sigismund of Austria and the other for himself, he forbad further damage, and ordered the stone to be suspended in the parish church."

All unprejudiced persons believed from this and other similar accounts that the stones had in fact fallen from the sky; but in the latter half of the eighteenth century the scientific men of the time threw doubts on the origin of these supposed sky-stones and looked upon the reports of their fall as merely fables. When, in July 1790, a shower of stones fell at Barbotan (dep. Landes) in Gascogne a full report of the occurrence was prepared from the statements of several observers and signed by the mayor for presentation to the Paris Academy of Sciences. This report was received unfavourably, and Bertholon in his remarks upon it in the Journal des Sciences added: "How must we grieve to-day to see an entire municipality join in giving serious credence to popular tales which can but excite the pity, not only of physicists, but of all reasonable people."

Four years later Chladni, the discoverer of sound figures, concluded, from the observations respecting the Pallas iron and other meteorites: firstly, that stones and masses of iron have fallen from the sky and the historical accounts relating to them must be accepted; secondly, that the phenomena are identical with those presented

*) Taken from "An introduction to the study of meteorites, with a list of the meteorites represented in the [British Museum] collection". By L. Fletcher, 10th edition, 1908. A piece weighing 458 grams of the Ensisheim meteorite is exhibited in the British Museum.

by fire-balls, and that meteorites themselves are nothing other than such burning masses; thirdly, that these masses are of cosmic origin, having come to the earth from outer space. The subject still remained controversial until the undoubted falls at Siena in Tuscany on 16 June 1794, Wold Cottage in Yorkshire on 13 December 1795, Krakhut in India on 19 December 1798, and especially at L'Aigle in Normandy on 26 April 1803. After the last of these occurrences the celebrated physicist Biot was instructed by the French Minister of the Interior to make an inquiry on the spot, and he was able to completely confirm the statements that a shower of stones had actually fallen from the sky.

At the present time the extra-terrestrial origin of meteorites is universally recognized as an undoubted fact; and while in former times collectors were ashamed to include in their collections a stone supposed to be of celestial origin, to-day these form the most valuable portions of the large mineral collections in London, Vienna, Berlin, Paris, Tübingen, Budapest, New Haven, Washington, New York, and other cities, the rarer pieces being valued at their weight in gold.

Manganese Ores.

The manganese ores are compounds of manganese with oxygen, with oxygen and water, or with carbonic acid. Whilst the compound of iron with carbonic acid is of great importance as an ore, the corresponding manganese compound is practically only of interest as a mineral. To make the list of manganese minerals more complete we must also mention two compounds with sulphur, namely the disulphide MnS_2, which as the mineral hauerite is related not only chemically but also crystallographically to iron-pyrites, and the monosulphide MnS (alabandite) possessing a similar relation to zinc-blende. Finally, there are several silicates and phosphates containing manganese, but these are of little or no importance as ores. The more important manganese minerals may then be listed as follows: —

Pyrolusite and Polianite, MnO_2.	Rhodochrosite, $MnCO_3$.
Hausmannite, Mn_3O_4.	Hauerite, MnS_2.
Braunite, Mn_2O_3.	Alabandite, MnS.
Manganite, $Mn_2O_3 . H_2O$.	Rhodonite, $MnSiO_3$.
Psilomelane and Wad.	

All of these minerals, with the exception of polianite and braunite, are represented on plates 33, 34 and 35.

Pyrolusite and **Polianite.** Pyrolusite (plate 33, figs. 1 and 2) forms radially fibrous masses, or less often granular masses, which are grey with a metallic lustre. It is very soft (H. = 2) and soils the fingers, and for this reason is known as soft manganese ore. The powder is black. In appearance it sometimes shows a certain resemblance to the totally distinct mineral stibnite, but the two may be readily distinguished by their fusibility; stibnite being readily fusible and pyrolusite infusible. With warm hydrochloric acid it liberates the greenish-yellow gas chlorine; and in a blowpipe bead of microcosmic salt it produces a violet colour. These reactions are, however, also the same for the other oxides of manganese.

Pyrolusite frequently results from the alteration of manganite and it is often stated that all pyrolusite has been derived from other ores of manganese; in any case it is, together with psilomelane, the most stable compound of manganese at the earth's

surface, and for this reason it is the most widely distributed. It also occurs as replacement-pseudomorphs after calcite and dolomite.

Localities for pyrolusite are: the Lindener Mark near Giessen (fig. 1), Puderbach in the Westerwald (fig. 2), Rossbach near Friedberg, Waldmichelbach in the Odenwald, Laisa near Battenberg, and the districts of Schmalkalden and Siegen, all of these being in Germany. Further, in the Chiaturi district in the Caucasus and many others; in fact at all the localities which will be mentioned below for manganese ores.

Polianite is another mineral with the same chemical composition as pyrolusite, the formula for both being MnO_2, corresponding to 63·2 % of manganese and 36·8 % of oxygen. This mineral is, however, much harder (H. = 6), for it scratches glass and does not soil the fingers. Crystals of polianite are tetragonal, but are of rare occurrence and usually very indistinct. Like pyrolusite, the colour is also grey with a metallic lustre, but the aggregates of the mineral are usually more granular and on the exterior they present a faceted crystalline appearance. Polianite is quite a rare mineral and is found only at Platten in Bohemia.

Psilomelane, like wad, differs from the other ores of manganese in being amorphous without any indications of crystalline structure. It sometimes has a concentric shelly structure (plate 33, fig. 5), and the external surface may be stalactitic (figs. 3 and 5), reniform (fig. 4), mamillated or botryoidal. In the interior it is dark iron-grey and dull, but on the exterior rounded surfaces it is black and often with a brilliant polish, hence the German name "schwarzer Glaskopf" (fig. 4). The hardness is rather high (H. = $5^1/_2$—6), and the mineral is consequently sometimes known as hard manganese ore; the specific gravity is 4·2—4·3.

The chemical composition of psilomelane is very variable and cannot be satisfactorily expressed by a formula. Manganese dioxide, MnO_2, is the principal constituent, together with some manganous oxide, MnO; and there are also several other oxides, the presence of which would scarcely be expected in this mineral, namely oxides of barium, potassium, copper, cobalt, silicon and lithium, whilst all contain a variable amount of water. The chemical reactions of psilomelane are the same as those for pyrolusite, but in addition the mineral gives off water when heated in a bulb-tube.

Psilomelane is found in association with limonite in the Siegen district in Westphalia and at many other localities, and with manganese ores at all the places mentioned above for pyrolusite.

Wad is another manganese ore of very variable chemical composition, but it is readily distinguished from psilomelane by its softness and porous character. The porosity is such that the mineral floats on water, and owing to its softness and looseness of texture it soils the fingers. It occurs as earthy and reniform masses of a dull black colour, and sometimes forms a coating on psilomelane (plate 33, fig. 7, here with an iridescent tarnish). The localities are the same as for pyrolusite.

Manganite. The manganese ores so far considered possess either no crystalline form or are very indistinctly crystallized; manganite, on the other hand, frequently occurs as well-developed crystals, which are rhombic with a prismatic habit. In plate 34, fig. 5, the sharply-developed rhombic prisms are terminated by a smooth base; in fig. 6 the prisms are deeply striated vertically and have drusy basal planes; and in fig. 7 the prisms are terminated by faces of a dome in addition to the drusy basal planes. Smaller crystals are often rich in terminal faces. The crystals possess a perfect cleavage in one direction parallel to the brachy-pinacoid.

The colour of manganite is dark steel-grey to iron-black, but the streak is brown, and this affords an easy means of distinguishing the mineral from other manganese

oxides. The hardness is $3^1/_2$—4, and the specific gravity 4·3. In addition to crystals, fibrous and columnar aggregates are common.

Manganite is a hydrated oxide of manganese with the formula $Mn_2O_3 . H_2O$; or it is probably more correctly to be considered as a manganese hydroxide MnO . OH, since the water it contains is expelled only at temperatures above 200° C. When subjected to weathering the mineral alters to pyrolusite; it loses water and becomes softer, and the streak is then black.

A very common associate of manganite is barytes (shown in fig. 5), and these two minerals form veins in porphyrite at Ilfeld in the Harz; at which locality the best crystallized specimens are found (plate 34, figs. 5—7). Other localities for crystals are Ilmenau and Oehrenstock in the Thuringian Forest, Upton Pyne near Exeter, Botallack mine in Cornwall, Granam in Aberdeenshire, Böhlet in Sweden, Negaunee in Michigan, Pictou in Nova Scotia. Massive material with a columnar structure occurs at these and other localities together with various ores of manganese.

Hausmannite forms small, acute tetragonal pyramids (plate 34, fig. 4), which are often grown together in twin position. Their colour is black and the lustre sub-metallic; the hardness is $5^1/_2$, and the specific gravity 4·8. The chemical formula of this oxide of manganese is Mn_3O_4, or perhaps more correctly $MnO . Mn_2O_3$. The chemical reactions are the same as for pyrolusite, and this mineral is best recognized by its crystalline form. It is found at Oehrenstock near Ilmenau in the Thuringian Forest (fig. 4); and in large amounts at Långban to the north of Filipstad in Wermland, at Pajsberg near Nordmark, and at Jakobsberg in Örebro; at all these Swedish localities the manganese ore occurs in connection with dolomite. Crystals are also found in a haematite mine at Bigrigg near Egremont in Cumberland.

Braunite also crystallizes in the tetragonal system, forming very small pyramids with angles not much different from those of the regular octahedron. The crystals are black, and are, as a rule, quite small and rough. The chemical composition can be expressed by the formula Mn_2O_3, but the compound is not simply manganese sesquioxide, being rather a manganous salt of manganic acid $MnMnO_3$. This mineral is found in Thuringia and at the Swedish localities mentioned above for hausmannite.

Rhodochrosite or manganese-spar. All the manganese ores dealt with above are black in colour, but in rhodochrosite and rhodonite the colour is a beautiful rose-red.

In crystalline form and chemical composition, rhodochrosite is closely related to chalybite and calcite, belonging to the same isomorphous group of rhombohedral carbonates. The crystals have the form of the primary rhombohedron (plate 34, fig. 3) with angles of 107° between the faces, or of the scalenohedron (fig. 1); those represented in the figures are more sharply developed and larger in size than the crystals commonly to be met with. Often the rhombohedral crystals show a saddle-like curvature and are confusedly aggregated. More frequently the mineral occurs in globular or botryoidal forms with an internal granular structure, and it is then sometimes known as raspberry-spar (fig. 2). Being a carbonate ($MnCO_3$), rhodochrosite effervesces in warm hydrochloric acid with the liberation of carbon dioxide. The presence of manganese is readily shown by the violet colour which the mineral imparts to a blowpipe bead of microcosmic salt. When weathered, the mineral becomes black and passes into manganese oxides. Owing to this instability, rhodochrosite is a mineral of quite rare occurrence, whilst fine crystals are still rarer. The latter are found in cavities in limonite at Sayn-Altenkirchen (fig. 1) and Horhausen in Rhenish Prussia; in the metalliferous veins of Freiberg in Saxony and Kapnik in Hungary. Massive material occurs as beds in limestone at Vielle and Las Cabesse (dep. Ariège) in the Pyrenees, and in province Huelva in Spain. Large

rhombohedra (fig. 3) are found with iron-pyrites at Alicante in Lake County and at other places in Colorado.

Rhodonite is a silicate of manganese with the formula $MnSiO_3$. In crystalline form and chemical composition it is related to the pyroxenes, and in the scientific classification of minerals it is placed in the pyroxene group. Here we consider it with the ores of manganese, since by weathering it gives rise to these, and it is itself occasionally mined as an ore; at the same time, however, we might place it with the precious stones, since the mineral has a certain application in this direction. Crystals are triclinic, and all the faces and edges are inclined at oblique angles. In plate 35, fig. 5, the large crystal is bounded by the base (the large face above), large faces of the vertical prisms (to the front and right) and narrow faces of the macro- and brachy-pinacoids; on the smaller crystals on the same specimen small pyramid faces truncate the edges between the base and the prism. Other crystals are more pointed in habit and much smaller. Like the pyroxenes, this mineral possesses two directions of good cleavage parallel to the faces of the prisms, the angle between which is $87^1/_2{}^0$.

The characteristic rose-pink colour of the mineral is shown in the imperfect crystal in fig. 4, and on the fractured surface to the left in fig. 5 (the colour being elsewhere obscured by a grey coating on the faces of the crystals). The hardness is $5^1/_2$—$6^1/_2$, and the specific gravity 3·5—3·6. The mineral is only slightly attacked by hydrochloric acid; it is not readily fusible, and in a bead of microcosmic salt gives the usual violet colour due to manganese. More frequent than crystals are compact granular masses, which are almost invariably marked with black veins and patches; these are due to the alteration of the mineral along cracks by weathering, with the production first of a hydrated manganese silicate and then of black oxide.

Small, but very perfect crystals are found in the iron mines at Pajsberg in Sweden; and large, rough crystals are met with in the zinc mines of Franklin Furnace in New Jersey. The latter contain 5—$7^1/_2$ per cent. of zinc oxide and are known as fowlerite.

Massive rhodonite is found at Elbingerode in the Harz, at Långban in Sweden; and especially at Ssedelnikova near Ekaterinburg in the Urals, where it is quarried and cut in Ekaterinburg into various small articles and ornaments. Large masses occur together with massive rhodochrosite in the deposits of manganese ore in province Huelva in Spain.

Hauerite is one of the two sulphides of manganese which occur rarely as minerals, this being the disulphide with a formula MnS_2 and corresponding to iron-pyrites. Crystals are cubic and usually have the form of the regular octahedron (plate 35, fig. 1) or of the octahedron in combination with the cube (fig. 2). Sometimes on small crystals the faces of a pentagonal-dodecahedron may be present; the mineral thus being hemihedral with parallel faces like iron-pyrites. Crystals are found in a sulphur mine at Raddusa in province Catania in Sicily, where they occur with gypsum embedded in clay: a similar occurrence is met with at Kalinka in Hungary.

Alabandite is the monosulphide of manganese, MnS, and this also crystallizes in the cubic system, but with tetrahedral hemihedrism: in its chemical formula and crystalline form it thus shows a relation to zinc-blende. The exceptionally large crystals shown in plate 35, fig. 3, though apparently a combination of the octahedron with the cube, are really a combination of the two tetrahedra with the cube. Twin-crystals also occur (one is shown to the left of the large simple crystal in fig. 3), the twin-plane being a tetrahedron face as in text-fig. 142. The mineral possesses perfect cleavages parallel to the faces of the cube (in zinc-blende the cleavage is dodecahedral); its colour is black, but the streak

is dark-green. Alabandite is a rare mineral; it is found at Nagyag and Offenbanya in Transylvania, at Kapnik in Hungary, and a few other places.

Occurrence of manganese ores. — Only the black oxides are of any importance as ores of manganese, and usually several of these occur together in the same deposit. Thus pyrolusite, psilomelane and wad, or hausmannite and braunite, are found together in beds in connection with limestone or dolomite. On the other hand, manganite more frequently occurs in veins, though it is never altogether absent in the bedded deposits. The largest deposit in Germany is that of the Lindener Mark near Giessen, where the ore consists of pyrolusite, psilomelane, wad (plate 33) and an earthy manganese ore rich in iron; polianite and manganite are here rare. These form beds of very varying thickness on Devonian limestone and are overlain by clay, so that they can be worked in open quarries. The annual production amounts to 100,000 tons of ore. Beds of manganese ore with a similar mode of occurrence are also found at Friedberg and in the Odenwald, thought here the limestone is of Permian age (Zechstein). The Swedish ores are also associated in the same way with limestone or dolomite, but here the manganese minerals are principally hausmannite and braunite. The invariable association of limestones with such beds of manganese ore can scarcely be accidental, but the exact relations are not quite clear: either the manganese was contained as traces in the limestones and concentrated by the weathering and solution of the rock; or the limestone may have caused the precipitation of the manganese from springs (p. 70). The most extensive manganese mines are those of Russia where new deposits are continually being open up. The ore, consisting mainly of pyrolusite, is at present won in the governments of Kutais and Tiflis in Caucasus, in governments Perm and Orenburg in the Urals, in government Ekaterinoslav in South Russia, and in the government of Semipalatinsk in Siberia. The richest deposits are those of Chiaturi in the Shavpan district in the western Caucasus; here, in the year 1901, the production amounted to 800,000 tons of ore. Rich manganese deposits are also met with in Brazil, Greece, Chile, Spain and Japan.

Applications. — Manganese is used in large quantities in the manufacture of iron (white pig-iron); its presence favours the chemical combination of carbon with the iron, and a manganiferous iron can be more readily freed from impurities by the Bessemer process than one not containing manganese. The bulk of manganese ores is used in the smelting of iron, and the demands in this direction have led to a continued increase in the production. Pyrolusite is also used for many other purposes: for example, for the manufacture of chlorine and bleaching powder, though not so much as formerly, since at the present time chlorine is largely obtained by the electrolysis of alkali chlorides. In the manufacture of glass, pyrolusite is used for obtaining a colourless product: the cheaper qualities of glass always contain some iron, which imparts a yellow or green colour, and by the addition of pyrolusite to the molten glass this colour is neutralized. In the potteries, pyrolusite is used to give a violet-coloured glaze, and pyrolusite and iron to give a brown glaze. Earthy pyrolusite is used in the manufacture of black mosaic tiles, for making galvanic cells, and in the preparation of potassium manganate and permanganate.

Most of the manganese ore imported into England comes from Russia, Brazil, Greece, Chile and Madras; while the quantity from Spain, European Turkey and Japan has considerably fallen off.

Nickel Ores.

The number of minerals from which nickel is obtained in any quantity is only small, being in fact limited at the present day to nickeliferous pyrrhotite (p. 150) and garnierite, a hydrated nickel silicate. Some few others have formerly been of importance as ores, and for this reason they will receive mention here. Nickel is always present in meteoric iron. The more important nickel minerals are the following: —

Pyrrhotite, FeS + NiS.	Gersdorffite, NiAsS.
Millerite, NiS.	Chloanthite, $NiAs_2$.
Niccolite, NiAs.	Annabergite, $Ni_3As_2O_8 . 8 H_2O$.
Breithauptite, NiSb.	Garnierite.

The metals nickel and cobalt are very closely allied to one another and in a lesser degree to iron, and the compounds they form are very similar. Their minerals fall into isomorphous groups (p. 143) and frequently contain more than one of the metals replacing each other in equivalent amounts.

Millerite forms very thin, hair-like or needle-like crystals, with a brass-yellow colour and metallic lustre, which are frequently aggregated into divergent tufts (plate 35, figs. 8 and 9). These crystals are very long and slender hexagonal prisms, and sometimes have a helical twist about their length. Owing to the delicate form of the crystals, this mineral is also sometimes known as hair-nickel or capillary pyrites. It has been suggested that in all cases millerite has been formed by a molecular transformation of beyrichite, a rare mineral with a grey metallic colour. The two minerals are identical in chemical composition, NiS, and have the same prismatic form, so that the change only affects the internal structure and the colour. Beyrichite has a specific gravity of 4·7 and millerite 5·9. The mineral is dissolved by nitric acid giving a green solution of nickel nitrate.

Millerite occurs with copper-pyrites in the Hilfe Gottes mine at Nanzenbach near Dillenburg in Nassau (plate 35, figs. 8 and 9); and also in the Friedrich mine at Wissen, and at Gladenbach in Rhenish Prussia, where formerly the mineral was mined. Very fine, acicular crystals are found in crevices in nodules of clay-iron-stone at Neunkirchen in the Saar coal mining district, and at Merthyr-Tydvil in South Wales. Other localities are: Johanngeorgenstadt in Saxony; the Gap mine in Lancaster Co., Pennsylvania; St. Louis in Missouri; the Sterling mine at Antwerp, New York; and abundantly in quartz at Benton in Saline Co., Arkansas.

Niccolite differs chemically from millerite in containing arsenic instead of sulphur, it being nickel arsenide NiAs. In their external appearance these two minerals are quite different, niccolite having a metallic copper-red colour and usually occurring in compact masses (plate 35, fig. 7). On account of its characteristic copper-red colour, this mineral was very early known in Germany as "Kupfernickel" (i. e. copper-nickel), although it contains no copper. The names nickel and cobalt are themselves rather names of disgrace: the former means in German 'worthless', and was applied to this mineral because it was useless as a copper ore; and the latter is from Kobold, the demon of the German mines. An old mineralogical treatise dated 1759 remarks: "Kupfernickel is a cobaltic coppery degeneracy" and "Kupfernickel is not only an indication of cobalt, but is itself a cobalt though more stupid". The present mineral could scarcely be mistaken for native copper, since it is hard (H. = $5\frac{1}{2}$) and brittle, whilst copper is soft and malleable; its streak is black, that of copper being red. Niccolite is soluble in warm nitric acid giving a green solution, which on cooling deposits brilliant, colourless

octahedra of arsenic trioxide. When heated before the blowpipe on charcoal, it emits arsenical fumes with the well-known garlic-like odour.

Crystals are of rare occurrence, and are always indistinctly developed; they belong to the hexagonal system, and are usually seen as the tips of hexagonal pyramids closely clustered together. Usually the mineral occurs as compact masses, which on weathered surfaces are coated with green, earthy annabergite. This is the hydrated nickel arsenate, $Ni_3As_2O_8 . 8 H_2O$, which is always present as a product of weathering on arsenical nickel ores; its colour somewhat resembles that of garnierite (fig. 12), but is a paler apple-green.

Niccolite occurs in association with silver ores in veins traversing crystalline schists at Schneeberg, Annaberg and other places in Saxony; at Joachimsthal in Bohemia; and with cobalt ores and barytes in veins in the Kupferschiefer district of Sangerhausen, Mansfeld and Richelsdorf in Germany. It has also been found in some of the Cornish mines. The mineral has been used for the extraction of nickel and for the preparation of white arsenic.

Very similar to niccolite is the species *breithauptite*, which contains antimony in place of arsenic, its chemical formula being NiSb. It is found embedded in calcite at Andreasberg in the Harz. Isomorphous mixtures of these two compounds are also known.

Gersdorffite, or nickel-glance, crystallizes in regular octahedra (plate 35, fig. 10), with sometimes small faces of the cube and the rhombic-dodecahedron, and rarely of the pentagonal-dodecahedron; the mineral is therefore cubic with pentagonal hemihedrism, having the same symmetry as the more common mineral cobalt-glance. These two minerals are also closely related chemically, nickel-glance being NiAsS, and cobalt-glance the corresponding cobalt compound CoAsS. Crystals of nickel-glance are dull and greyish-black on their exterior, but freshly fractured surfaces are steel-grey with a metallic lustre. The hardness is 5—5½. The mineral is readily decomposed by weathering and becomes coated with a green crust of annabergite and nickel-vitriol.

The specimen with large crystals and associated chalybite represented in fig. 10 is from Lobenstein in Thuringia; smaller crystals and massive material are found in the mineral-veins of the Rhenish district and of the Harz, but the mineral is one of rare occurrence.

Chloanthite and the very similar mineral smaltite show more than any others the close relation which exists between nickel and cobalt. Ideally, chloanthite is a diarsenide of nickel, $NiAs_2$, and should contain 28·1 per cent. of nickel and 71·9 per cent. of arsenic; whilst smaltite is the corresponding cobalt compound, $CoAs_2$. As a matter of fact, however, neither of these compounds is ever found in the pure state, but they always contain cobalt, nickel and iron isomorphously replacing one another. There is thus no hard and fast line between chloanthite and smaltite, and they pass insensibly one into the other. The members of the series which are richer in nickel and on weathering consequently become encrusted with green annabergite are placed with chloanthite.

The crystals are cubic, usually with faces of the cube and the octahedron (plate 35, fig. 11), and have a metallic lustre with tin-white or steel-grey colour, but frequently a greyish tarnish. The mode of occurrence and the applications of chloanthite are the same as for smaltite, and will be mentioned under the latter mineral.

Garnierite is one of the most important of the ores of nickel. It occurs in compact or earthy masses which are quite soft and greasy to the touch, while the fine green colour is a feature which attracts the eye (plate 35, fig. 12). The colour varies in shade and is not always so rich as represented in the figure; it is usual to distinguish the darker green varieties as *noumeite* (after the locality, Noumea in New Caledonia), and the paler green varieties as *garnierite* (after Jules Garnier, the discoverer of the New

Caledonian nickel ores). This distinction is, however, of little importance, for the material is not a definite chemical compound and consequently not a distinct mineral species, but only a mixture. It contains silica, magnesia, nickel oxide and water in variable proportions, and may be considered as a nickel-bearing hydrated magnesium silicate allied to serpentine; the amount of nickel oxide contained in pure selected samples varies from 3 to 30 per cent. The mineral occurs in veins traversing a serpentine-rock, and like this it has been derived by the weathering of an olivine-rock, the olivine of which contained nickel. With the weathering of the olivine the nickel was set free and was deposited in crevices as a concretionary layer on blocks of the weathered rock.

The largest and richest deposits of garnierite are those near Noumea in New Caledonia, and beds up to ten metres in thickness also occur in Douglas County, Oregon. Of less importance is the occurrence at Gläsendorf and Kosemütz near Frankenstein in Prussian Silesia, where the mineral, containing 2—$3^1/_2$ per cent. of nickel, has recently been mined. Pure nickel can be more readily extracted from garnierite than from ores which contain their nickel in combination with sulphur and arsenic, and it is therefore only since discovery of the garnierite deposits in New Caledonia that the nickel industry has attained its present importance.

Applications of nickel. — At the present time nickel ores are mined only in New Caledonia, Canada and the United States. During the year 1901 the New Caledonian ores treated in England, France and Germany yielded 5000 metric tons of metallic nickel, while Canada and the United States produced 3600 tons. The price of nickel is about three shillings per kilogram.

Nickel is used for the construction of a variety of household vessels and utensils, and for nickel-plating. Steel with an addition of nickel is greatly increased in toughness, and on this account nickel-steel has recently been used for the armour plates of battleships. An alloy of copper, zinc and nickel is known as German silver (p. 114). The nickel coins of Germany contain 25 parts of nickel and 75 parts of copper; those of other countries (Switzerland and Austria) contain more nickel.

Cobalt Ores.

The cobalt ores are analogous in composition to the ores of nickel, though the simplest compounds, corresponding to millerite and niccolite, are not known in nature. On the other hand, the rare mineral skutterudite, consisting of cobalt triarsenide, $CoAs_3$, has no nickel analogue. With these exceptions, the cobalt minerals correspond with the nickel minerals, and we have the following pairs: cobalt-glance and nickel-glance, smaltite and chloanthite, erythrite and annabergite. Oxide of cobalt occurs mixed with oxides of manganese and iron, forming a cobaltiferous wad known as black earthy cobalt or asbolite. The arseno-sulphide of cobalt, CoAsS, is dimorphous, occurring as the pyritohedral-cubic cobalt-glance and as the rhombic glaucodote. The more important cobalt minerals are thus the following: —

Cobalt-glance and Glaucodote, CoAsS.	Erythrite, $Co_3As_2O_8 . 8\,H_2O$.
Smaltite, $CoAs_2$, and Skutterudite, $CoAs_3$.	Asbolite (a mixture).

The best test for cobalt is given by the blue colour which it imparts to a blowpipe bead of microcosmic salt or borax, and cobalt ores may always be detected by this characteristic reaction.

Cobalt-glance, or cobaltite, is a mineral which can always be recognized by the form and colour of its crystals. These are cubic with pentagonal hemihedrism exactly like those of iron-pyrites in form, the two minerals cobaltite and iron-pyrites being isomorphous. Several isolated crystals are represented in plate 36: fig. 1 shows the pentagonal-dodecahedron, and fig. 2 the same with small faces of the cube; fig. 4 the cube in combination with the pentagonal-dodecahedron; figs. 4 and 5 the octahedron; and figs. 6, 7 and 8 the combination of the octahedron and the pentagonal-dodecahedron developed to the same extent, giving the so-called icosahedron. The accompanying text-fig. 143 shows this combination drawn with ideal regularity; the octahedron faces are equilateral triangles, and those of the pentagonal-dodecahedron are isosceles triangles. In the natural crystals these two sets of faces are physically quite different, and may be readily distinguished; the octahedron faces being bright and smooth, and the pentagonal-dodecahedron faces striated or dull.

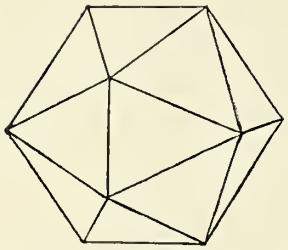

Fig. 143.
Crystal of Cobaltite.

The colour of the crystals is silver-white with a tinge of red, or steel-grey with a tinge of violet, and the streak is greyish-black. There are distinct cleavages parallel to the faces of the cube. The hardness is $5^1/_2$, and the specific gravity a little over 6. Corresponding to the formula CoAsS, the mineral, when pure, contains 35·4 per cent. of cobalt, but owing to the partial replacement of cobalt by iron the former may be as low as 30 per cent. Crystals of cobaltite are readily recognized, and the massive ore is easily determined before the blowpipe; it gives an arsenical odour, with soda the hepatic reaction, and in the microcosmic bead a blue colour.

Crystals of cobaltite are found together with copper-pyrites (plate 36, fig. 9) in veins in gneiss at Tunaberg in Sweden (figs. 1, 3—7 and 9); embedded in a quartzose mica-schist at Skutterud in the parish of Modum in Norway (figs. 8 and 10); and at Håkansboda in Westmanland, Sweden (fig. 2). At Dashkessan in government Tiflis in Caucasia there is a bed of pure cobaltite with an average thickness of 0·2 metre.

Glaucodote has the same chemical composition as cobaltite, though here a larger proportion of the cobalt is replaced by iron, and in most instances iron predominates. Crystals from Håkansboda contain 15 per cent. of cobalt and 19 per cent. of iron, so that the formula must be written as (Fe,Co)AsS, and the mineral may be considered to be a richly cobaltiferous mispickel (p. 148). The crystals are rhombic with angles very close to those of mispickel. In plate 36, fig. 11 shows a simple crystal and fig. 12 an intercrossing twinned crystal. The crystals here represented are prismatic in habit, but it is usual to take the long faces in fig. 11 and the striated faces in fig. 12 as the brachy-dome, and the small terminal faces as the vertical prism, the twin-plane then being a face of the macro-dome. The hardness is 5, and the specific gravity 6·0.

The finest crystals are those from Håkansboda in Sweden, where they occur with crystals of cobaltite embedded in copper-pyrites. Crystals in gneiss from Franconia, in New Hampshire, approach more nearly to mispickel in composition, and are called danaite.

Smaltite. This, the the most important ore of cobalt, is a compound of cobalt and arsenic $CoAs_2$, but a portion of the cobalt is invariably replaced by equivalent amounts of nickel and iron. Theoretically, the percentage of cobalt should be 28.1, but it scarcely ever reaches as much as 20, and is often less than this.

Crystals are cubic and are usually rather roughly developed; thus the large crystal shown in plate 36, fig. 13, is a combination of the cube and octahedron (the large surface to the front being a cube face), and the crystals in fig. 14 are bounded

by the cube, octahedron and rhombic-dodecahedron. The crystal in fig. 15 has been broken across and shows, in the interior, shelly lines of growth, so that we see here a zonal structure in an opaque mineral. The reddish colour seen on these crystals is due to a partial alteration of the material by weathering with the formation of earthy erythrite. Dendritic and rod-like forms of growth are also met with, while compact, granular masses of the mineral are of common occurrence.

Smaltite occurs in association with native bismuth, niccolite, silver ores and quartz in veins traversing granite and gneiss at Schneeberg in Saxony and at Wittichen in Baden; and under very similar conditions, together with large amounts of native silver, near Lake Temiskaming in northern Ontario in Canada. With barytes, niccolite and asbolite it occurs in veins in the Kupferschiefer (copper-shale) at Richelsdorf and Bieber in Hesse, and at Glücksbrunn and Kamsdorf in Thuringia. The beds of the Zechstein formation, of which the Kupferschiefer (p. 104) forms a part, are intersected by planes of faulting with downthrows of 10 to 20 metres, and along the crevices the various minerals have been deposited; the cobalt and nickel ores are collected mainly against the downthrown Kupferschiefer, and these portions of the veins are called "backs", and the ores "cobalt backs".

Erythrite, or cobalt-bloom. This is a hydrated arsenate of cobalt with the formula $Co_3As_2O_8.8H_2O$, corresponding to the hydrated arsenate of nickel, annabergite or nickel-bloom. The former is of a beautiful crimson or peach-red, while the latter is of an equally characteristic pale apple-green colour. Annabergite is found only in an earthy and massive form, whilst erythrite is sometimes found as acicular crystals, of a fine red colour, aggregated in radiating tufts or stellate groups (plate 36, fig. 15); more frequently, however, it occurs as an earthy encrustation on smaltite, to the weathering of which it owes its origin.

Specimens of crystallized erythrite come from Schneeberg in Saxony, while the earthy mineral occurs at all the localities at which smaltite is known. Sometimes the earthy erythrite is encrusted with small, white, spherical masses with a radially-fibrous structure and very like spots of mould in appearance: this is the mineral pharmacolite, a hydrated calcium arsenate, which has been formed by the action of the weathering products of smaltite on the neighbouring limestone.

Applications of cobalt. — Attempts have recently been made to use metallic cobalt for the same purposes as metallic nickel, but apart from this almost the only application of cobalt depends on its property of imparting a fine blue colour to glass and porcelain. This use of cobalt has been known since very early times, for blue cobalt glass has been found in the tombs of the ancient Egyptians and in the ruins of Troy. In the preparation of blue glass, the cobalt ore, after roasting, is simply added to the molten glass. The blue glass so obtained, when powdered and the finer particles collected by washing in water, gives smalt or cobalt-blue, which owing to it resistance to heat and solutions, is much used as a pigment. The blue colour of porcelain is produced by black cobalt oxide, which is taken up by the glaze during the burning.

Since olden times the cobalt industry has been centred in the Saxon Erzgebirge, and the smalt is there manufactured in colour works belonging both to the state and to private firms. Now, however, a sufficient quantity of ore cannot be mined on the spot, and the ore is imported from Sweden, Russia and New Caledonia. The New Caledonian ore is an earthy mixture of limonite with manganese oxides and about 4 per cent. of cobalt oxide; this is known as black earthy cobalt (asbolite). Important deposits of cobalt ore (smaltite) have recently been discovered in northern Ontario.

Tungsten Compounds.

Of the few tungsten compounds occurring in nature, only one is of any importance as an ore; this is wolframite, a tungstate of iron and manganese $(Fe,Mn)WO_4$. Scheelite, a tungstate of calcium $CaWO_4$, is of importance as a mineral, but the others (stolzite $PbWO_4$ and hübnerite $MnWO_4$) are of quite rare occurrence.

Scheelite, a mineral named in honour of the Swedish chemist Scheele, the discoverer of the metal tungsten, is of especial interest to crystallographers. The crystals belong to the tetragonal system and are usually bounded by a single square pyramid, which even in combinations predominates and gives rise to the characteristic pyramidal habit of the mineral (plate 37): tabular crystals are rare, whilst a prismatic habit is not known. When the pyramidal crystals are examined closely other small faces may sometimes be detected on their corners. In text-fig. 144 the predominating pyramid *e* is taken as a pyramid of the second order $P\infty$; the faces marked *o* belong to the primary pyramid *P* of the first order; and the faces *h* and *s* occupy the positions of eight-sided pyramids, but each of them have only half the full number of faces developed, these forms being hemihedral with parallel faces and having the symbols $\frac{3P3}{2}$ and $\frac{P3}{2}$ respectively. Scheelite is thus tetragonal with pyramidal-hemihedrism, and it affords the best example of this type of symmetry.

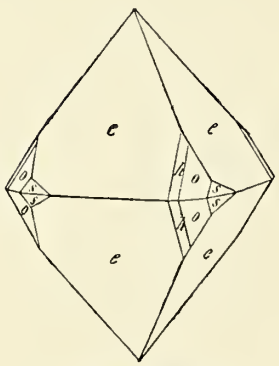

Fig. 144.
Crystal of Scheelite.

The crystals are usually yellow of various shades (plate 39, figs. 1—5), but sometimes grey or white (fig. 6); they are transparent to translucent, and may be bright or dull and rough. The hardness is $4^1/_2$—5, and the specific gravity 6·0. Parallel to the faces of the primary pyramid *o* there are good cleavages. The pure mineral contains 19·44% of lime (CaO) and 80·56 of tungstic oxide (WO_3), corresponding with the formula $CaWO_4$; often, however, a small proportion of the tungsten is isomorphously replaced by an equivalent amount of the closely allied metal molybdenum. The mineral is decomposed by hydrochloric acid, the calcium passing into solution and the tungstic oxide remaining behind as a yellow powder.

Scheelite only rarely shows any signs of alteration by weathering, nevertheless it does sometimes undergo a change, as proved by the occurrence of pseudomorphs of wolframite after scheelite (fig. 7).

The mineral is generally found in veins in granitic rocks and is then a common associate of tin-stone, but it may be unassociated with this and also tin-stone may occur without scheelite. Crystals are found in the tin-stone veins at Schlaggenwald (plate 37, fig. 6) and Zinnwald in Bohemia, at Ehrenfriedersdorf in Saxony, and in Devon and Cornwall. In other veins it is associated with flour-spar, as at the Riesengrund in the Riesengebirge in Bohemia (fig. 2), and at Fürstenberg in Saxony (fig. 1). Crystals also occur in crevices in hornblende-schist on the Little Mutschen in the Etzli-thal, and at Kamegg near Guttannen above Meiringen (fig. 4), in Switzerland; in the magnetite deposits at Traversella in Piedmont (fig. 5); at Dragoon in Arizona; and at Carrock Fell in Cumberland. Pseudomorphs of wolframite after scheelite (fig. 7) are from Lane's mine at Monroe in Connecticut.

Wolframite consists of an isomorphous mixture of tungstate of iron and tungstate of manganese in very variable proportions, $(Fe, Mn)WO_4$, sometimes the iron and sometimes the manganese predominating. With this variation in composition there is a corresponding variation in colour from brownish-black (containing more manganese) to pitch-black; the mineral is opaque with a semi-metallic lustre; the streak is reddish-brown to blackish-brown. The specific gravity is very high, varying with the chemical composition from 7·1 to 7·5.

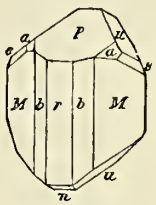

Fig. 145. Crystal of Wolframite.

Crystals are monoclinic, often with a rhombic habit, the mineral having been in fact formerly considered to be rhombic in crystallization. In plate 37, fig. 8, the large face to the front is the ortho-pinacoid (r in text-fig. 145), the vertically striated faces at the sides the vertical prism (M), while above are an ortho-dome (P) and one face of a clino-dome (u). The Naumannian symbols of the forms present on the crystal shown in text-fig. 145 are: —

$r = \infty P\bar{\infty}$, $b = \infty P\bar{2}$, $M = \infty P$, $P = -\frac{1}{2}P\bar{\infty}$, $n = \frac{1}{2}P\bar{\infty}$, $u = P\dot{\infty}$, $a = -P$, $s = -2P\dot{2}$.

Figs. 9 *a* and *b* show two views of a crystal twinned on the ortho-pinacoid; in the first the striated ortho-pinacoid and prism faces are set up vertically (as in fig. 8), while in the second the crystal is turned round to show more clearly the re-entrant angle at the top. Crystals of wolframite possess a very perfect cleavage parallel to the plane of symmetry, that is parallel to the clino-pinacoid, although this is not developed as a crystal face on any of the crystals here shown.

Crystals of wolframite are of comparatively rare occurrence, the mineral being more often met with as granular, columnar or fibrous masses. These may usually be recognized by the perfect cleavage with dark blackish-brown colour and sub-metallic lustre, and by the high specific gravity; and the determination may be confirmed by the following tests. When heated before the blowpipe for some time a fused globule of the mineral becomes magnetic, proving the presence of iron; the powdered mineral when fused with sodium carbonate and potassium nitrate gives a green colour characteristic of manganese; and in warm hydrochloric acid the mineral is decomposed leaving a yellow residue of tungstic acid.

Wolframite is a frequent associate of tin-stone, but it also occurs without this. Large crystals are met with in the veins of tin ore in the Erzgebirge of Saxony and Bohemia, and in many of the Cornish tin mines; the large crystal shown in fig. 8 is from Zinnwald in Bohemia. Finely fibrous masses, with occasionally minute crystals, are mined in Spain, which is the chief wolfram-producing country. The production of ore in the year 1900 amounted to 1958 tons in Spain, 188 tons in Queensland (at Wolfram Camp in the Hodgkinson mining field), 43 tons in Saxony, and 36 tons in Austria.

The metal tungsten finds an application in the manufacture of steel (tungsten-steel), and the greater the amount of tungsten added the harder and tougher is the product. An alloy of tungsten and aluminium, known as partinum, is used in the construction of automobiles. The pure metal is fusible only with great difficulty, but it can now be obtained by the Goldschmidt process, which has been described above under chromium. It is a very hard and heavy metal (sp. gr. 16), and would be suitable for projectiles if only it could be more easily worked. Quite recently, it has been employed as the metallic filament of incandescent electric lamps.

Molybdenum Compounds.

One of the native compounds of molybdenum has already been considered with the lead ores, namely wulfenite, the molybdate of lead $PbMoO_4$. There only remains to be mentioned here the sulphide MoS_2.

Molybdenite, or molybdenum-glance, forms tabular hexagonal crystals with narrow and deeply striated prism faces at the edges (plate 37, figs. 12 and 13), but more frequently it occurs as thin plates without definite outline embedded in the matrix. It is lead-grey with a metallic lustre and is opaque. Owing to its low degree of hardness (H. = 1) it readily marks paper. The crystals and scales possess a perfect cleavage parallel to their large surface, i. e. the cleavage is basal. Molybdenite resembles graphite more or less closely in appearance, but it may be distinguished from this by its lead-grey colour, much higher specific gravity (4·8), and by its chemical reactions. It is a compound of molybdenum and sulphur with the formula MoS_2; the presence of sulphur is best detected by the hepatic reaction.

Molybdenite is found together with tin ores at Altenberg in Saxony, Zinnwald and Schlaggenwald in Bohemia, and in Cornwall. It is also found in the neighbourhood of granite and other plutonic rocks at Auerbach in Saxony, at Carrock Fell in Cumberland, and in Nerchinsk in Siberia. Large crystals occur at Aldfield, Quebec, and at Kingsgate, New South Wales; and masses of some size in the Hodgkinson mining field in Queensland.

Molybdenite never forms extensive deposits, though it is practically the only source of molybdenum. It is used for the preparation of molybdenum compounds, which are mainly employed as chemical reagents; and recently it has been employed, like tungsten, in the manufacture of certain varieties of steel.

Uranium Compounds.

Pitchblende, or uraninite, though in itself a mineral of most unattractive appearance, is of special interest on account of the remarkable and mysterious properties possessed by some of its constituents. The rays emitted by these constituents cause the air to become a conductor of electricity, so that under their influence an electroscope or other electrically charged body is discharged; they are capable of passing through certain opaque substances, and acting in the dark on a photographic plate; and further, they cause barium platinocyanide to phosphoresce with a bright light. To what source of energy these phenomena are due is not quite clear, but they may possibly be caused by the projection of extremely minute particles of the substance itself from the main mass. This radio-activity of salts of uranium was first observed by the late Professor Henri Becquerel in 1896, and the rays have on this account been known as Becquerel rays; they are also known as uranium rays or radium rays. It has since then been found that the rays are not emitted by the uranium itself, but by other substances which are mixed with it in extremely minute quantities. One of these has been isolated and named radium, a chemical element which in the crystalline forms of its salts shows a close relation to barium. The other, known as radio-active bismuth or polonium, has not yet been isolated in a pure condition; and it is still questionable whether a second radio-active substance is present in pitchblende, or whether the radio-activity of bismuth may not be due to the presence of traces of radium.

The rays emitted by radium also cause diamond to phosphoresce brightly in the dark. We are thus furnished with an easy and certain means of testing the genuineness of a diamond, for neither glass nor rock-crystal display any appreciable phosphorescence when placed close to radium; ruby, sapphire and emerald are likewise not affected. Another, and still more remarkable feature presented by radium is its slow transformation into helium, as recently observed by Sir William Ramsay. The search of the alchemists for the philosopher's stone and the transmutation of the elements has thus been vindicated, and the very foundations of modern chemistry have been shaken. It is, however, not yet proved beyond doubt that radium is an element; its properties have not yet been completely investigated by physicists and chemists, and it may possibly prove to be a compound or a mixture.

The mineral pitchblende, in which this magic substance is contained, usually occurs as compact, opaque masses of a greenish-black or pitch-black colour and greasy lustre; the free surface of the masses is mamillated or reniform (plate 37, fig. 10). The mineral crystallizes in the cubic system, but crystals are small and of extremely rare occurrence. Like other minerals which occur in compact masses, pitchblende is not a pure chemical compound, but rather of the nature of a mixture. It consists mainly of uranium oxides, which may be present to the extent of 80 per cent., the remainder consisting of lead, iron, bismuth, antimony, thorium, lanthanum, yttrium, and traces of radium.

In order to demonstrate the presence of uranium, a little of the powdered pitchblende is dissolved in nitric acid, and the solution evaporated to dryness. Water and sodium carbonate are than added and a drop of the filtered solution is placed on a microscope slide together with a drop of acetic acid and allowed to evaporate. Small regular tetrahedra of sodium uranyl acetate are thereby formed und these are readily recognized under the microscope.

Corresponding with the variation in chemical composition of the mineral, there is a wide variation in the specific gravity, which ranges from 8·0 to 9·7. The hardness is 5—6. Before the blowpipe the mineral is infusible.

The principal locality for pitchblende is Joachimsthal in Bohemia, where it is found in the mineral-veins with ores of silver, bismuth, nickel and cobalt. Until ten years ago about 22 tons of uranium ore were obtained annually from these mines, but since the discovery of radium the output has been greatly increased. The mineral is also found in the Saxon Erzgebirge at Marienberg, Annaberg and Johanngeorgenstadt, also in Cornwall and Colorado, and as crystals in the felspar quarries of Norway, but never in more than small amounts.

Pitchblende is the crude material or ore from which all uranium compounds are prepared. Amongst other purposes, these are used for the manufacture of the green fluorescent uranium glass and for pigments used in painting on porcelain. In recent times they have acquired considerable importance by reason of their radio-active properties: besides being used in physical investigations, radium is extensively used for medical purposes. It possesses all the advantages of the Röntgen rays without their injurious effects, and the rays it emits can be applied directly and conveniently at all times without the use of any accessory apparatus. A small glass tube no thicker than a quill containing only a little more than a milligram of the radium salt has been found to be just as effective as an expensive and cumbersome electrical apparatus; and in the treatment of cancer better results have been obtained than with the Röntgen rays, whilst in its local application, for example in the nose or throat, it possesses an enormous advantage in addition to that of simplicity.

The fact that radium gives out both light and heat and is also capable of causing other substances to become luminous holds out the hope that this material may in the future play an important part in lighting. A very small quantity of radium causes a screen coated with hexagonal zinc sulphide to become brilliantly luminous, and since this phosphorescent light is unaccompained by the production of heat, there is no dissipation of a large proportion of the energy in this form, as in other methods of lighting. Were it not for the dangerous property it possesses of producing severe burns in the human skin, one would wish that this remarkable substance might be produced at a lower cost. Owing to its excessive rarity, its price is correspondingly high; in 1904 it was quoted at £400 per gram, while at the present time, with a demand greater than the supply, it is far higher.

The **"Uranium Micas"**. Whilst pitchblende is dull black and unattractive in appearance, many of the other compounds of uranium are brilliantly coloured and lustrous; their appearance is, in fact, rather suggestive of the phosphorescent colours which are induced in other substances by the Röntgen rays and the rays of radium. The most frequent of the naturally occurring compounds of uranium are platy in form and possess a perfect cleavage in one direction, so that they have a certain resemblance to the micas, and on this account they are referred to collectively as the "uranium micas". These minerals are hydrated compounds of uranium oxide with phosphoric or arsenic acid and in addition either calcium or copper: the more important are given below with their respective chemical formulae:

Cuprouranite, $CuO \cdot 2UO_3 \cdot P_2O_5 + 8H_2O$. Zeunerite, $CuO \cdot 2UO_3 \cdot As_2O_5 + 8H_2O$.
Calcouranite, $CaO \cdot 2UO_3 \cdot P_2O_5 + 8H_2O$. Uranospinite, $CaO \cdot 2UO_3 \cdot As_2O_5 + 8H_2O$.

Cuprouranite, or torbernite (plate 37, fig. 11) may be here briefly described as the typical representative of this group of somewhat rare minerals. It invariably has the form of thin square plates with a bright grass-green or emerald-green colour and a pearly lustre on the tabular face. A number of crystals are often closely and irregularly grouped together on the surface of the matrix. In their external form and in their optical characters the crystals conform with tetragonal symmetry: the large face with a square outline is the basal plane, at the edges of which are narrow faces of the square prism and pyramids. Parallel to the base there is perfect cleavage, and thin flakes can readily be separated from the crystals; when examined in convergent polarized light these show a uniaxial interference-figure (plate 4, fig. 1). The mineral is not harder than gypsum, and its specific gravity is 3·5. The presence of copper can readily be demonstrated by moistening a fragment with hydrochloric acid and holding it in the flame of a Bunsen-burner, when a green coloration is imparted to the flame.

Cuprouranite is found at Johanngeorgenstadt in Saxony and Joachimsthal in Bohemia, but the best and largest crystals come from Gunnislake, Redruth (plate 37, fig. 11) and Grampound Road in Cornwall.

Calcouranite, or autunite, is sulphur-yellow in colour, and, although its crystals are very similar in habit and appearance to those of cuprouranite, it crystallizes in the rhombic system. The same is also true of the siskin-green uranospinite, whilst the emerald-green zeunerite is tetragonal like cuprouranite. In all these uranium minerals, as well as in a few others, are there traces of radio-active substances.

Tin Ores.

Bronze, which is an alloy of copper and tin (p. 113), has been known since very early times, and in fact is closely connected with the development of the human race, for the bronze-age following after the stone-age preceded the age of iron. It is therefore clear that tin ore was known at this early period, but whether the bronze was obtained directly by smelting together ores of copper and tin or by alloying the metals is not known. When we consider the abundance of tin ore in the streams of certain districts and the ease with which it can be smelted it is not improbable that metallic tin also was known. In the Swiss lake-dwellings there have been found earthenware vessels, knobs and other articles coated with strips of tin-foil; and in the ancient graves on the island of Amrum off the coast of Schleswig-Holstein various objects made of tin have been discovered.

The rarity of objects of tin belonging to ancient times is, however, not surprising when we remember that metallic tin is subject to a remarkable kind of alteration or a disease of the metal itself. In a fresh condition tin is white and lustrous, and being

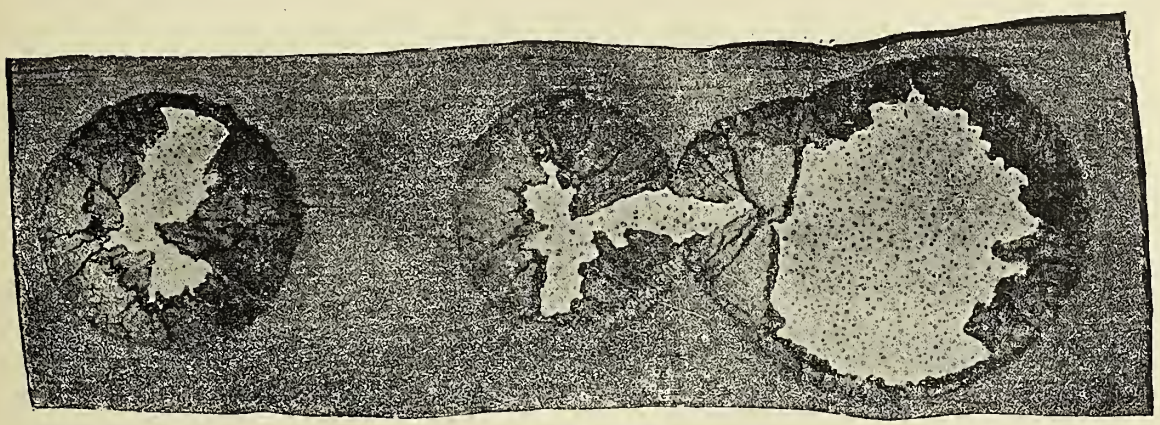

Fig. 146.
Strip of metallic tin attacked by the "tin pest". (After J. Fritsche).

malleable it can be hammered out into thin sheets (tin-foil). These characters are, however, not permanent, but the change that takes place is not the same as with other metals. Iron and copper chemically combine with the oxygen of the air and with water with the production of new compounds, iron passing into hydroxide of iron, and copper into malachite. On the other hand, tin undergoes no chemical change; it still remains metallic tin, but it gradually becomes grey and dull and falls to powder. This change is favoured by extreme cold and by dampness, but it also takes place in the dry. A tin vessel attacked by the "tin pest" cannot be saved, the alteration spreads and the tin becomes brittle and finally falls to powder. This powder is capable of infecting or inducing the change in other masses of tin, so that disease spreads until all the objects of tin in the immediate neighbourhood are destroyed. In text-fig. 146 is shown a strip of tin in which the alteration has spread outwards from three infected centres. Many instances of this destruction of tin even in recent times are known. Thus, in the year 1868 blocks of Banka tin in a store room in the custom-house at St. Petersburg were found to have been broken up by decay; and in a Russian imperial magazine in place of the tin uniform buttons little heaps of powder were found. During the winter of 1877 a consignment of Banka tin, sent on the railway from Rotterdam to

Moscow, arrived in the form of powder. The organ pipes in churches in Finland have been destroyed, and quite recently a large tin plate on the roof of the post-office at Rothenburg in Bavaria has been attacked by the "tin pest".

This alteration in tin is due to a change in the internal crystalline structure of the metal and is accompanied by an appreciable increase in volume, it is of the same nature as the gradual transformation of monoclinic sulphur to rhombic sulphur (p. 141), only in tin the change takes place much more slowly. By the action of heat the grey tin can be again converted into white tin, in the same way that rhombic sulphur can be again changed into monoclinic sulphur. Ordinary white tin which we use in everyday life is thus unstable at the ordinary temperature (about 20° C.), and is liable to alteration, more especially when subjected to a low temperature or when in contact with grey tin or a solution of a salt of tin.

In striking contrast with the universal application of metallic tin and bronze is the fact that these are obtained from a single ore of tin and further that this is quite limited in its distribution, being found at only a few spots in sufficient quantity for mining. This ore is tin-stone or cassiterite; the few other minerals which contain tin as an essential constituent are of rare occurrence and of no importance as ores. These include stannite (Cu_2FeSnS_4), franckeite ($Pb_5FeSn_3Sb_2S_{14}$), cylindrite ($Pb_3FeSn_4Sb_2S_{14}$), teallite ($PbSnS_2$), canfieldite (Ag_8SnS_6), and stokesite ($H_4CaSnSi_3O_{11}$).

Cassiterite, or tin-stone, is a compound of tin and oxygen, SnO_2, containing when pure 78·6 % of tin; usually, however, it contains some intermixed iron oxide causing a corresponding decrease in the amount of tin. When a fragment of the mineral is finely powdered and strongly heated on charcoal with sodium carbonate or potassium cyanide, beads of metallic tin are obtained, which are readily recognizable by their colour and lustre. The mineral is scarcely attacked by acids. The appearance of cassiterite does not at all suggest that it contains a large amount of a white metal: it is usually almost black, and only on splinters and fractured surfaces does it show a colophony-brown colour with translucency (plate 38, fig. 5). Less frequently the crystals are pale yellowish-brown (fig. 2), and exceptionally they are quite colourless. The faces of crystals often display a brilliant adamantine lustre. Since the mineral contains a heavy metal its specific gravity is correspondingly high, being 6·8—7. The hardness is 6—7.

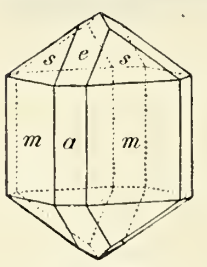

Fig. 147.
Crystal of Cassiterite.

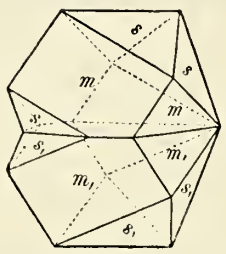

Fig. 148.
Twinned crystal of Cassiterite.

Well-crystallized specimens are not uncommon; the crystals belong to the tetragonal system, and the rarely occurring simple crystals (text-fig. 147) are bounded by prisms of the first and second orders, $m = \infty P$ and $a = \infty P\infty$, and pyramids of the two orders $s = P$ and $e = P\infty$. The isolated crystals shown in plate 38, figs. 1 and 2, have the same forms; in fig. 2 the pyramid $P\infty$ being larger than P. The faces of the pyramid P are inclined to one another at angles of $121\frac{3}{4}°$. The faces of the crystals may be either smooth or marked with more or less regular hillocks (fig. 3); a parqueted pattern on a prism face is represented in plate 19, fig. 8.

Almost invariably, crystals of cassiterite are twinned; and the twin-crystals present a certain resemblance in their shape to an upturned visor, and they are known to the Saxon miners as "Visiergraupen" or "Zinngraupen". This very characteristic form of cassiterite is represented in plate 38, figs. 3, 4 and 5, and in text-fig. 148. The twin-plane, which is the plane common to the two individuals of the twin, is a face of the

pyramid $P\infty$, being in text-fig. 148 a face which would truncate the upper edge of the pyramid *s*. The re-entrant angles on the outwardly bent portion of the twin are formed by the pyramid faces, which may be larger or smaller in size, giving a correspondingly larger or smaller cleft in the crystal; when these pyramid faces are altogether absent the prism faces meet across the twin junction, and the form more closely resembles a bent knee, as is more commonly met with in rutile. A knee-shaped twin of this kind is represented in fig. 6, where the crystal is placed with the twin-plane vertical and the narrow face of the prism of the second order to the front; standing up on the right is a third individual in twinned position to the portion immediately below. Repeated twinning, together with irregular grouping of crystals, gives rise to the kind of aggregates shown in figs 7 and 8.

Large crystals such as represented on plate 38 are not very common, the majority of crystals being smaller and less distinct, or the ore occurs as grains, often of microscopic size, scattered through the rock. Less frequently, the mineral forms compact, radially-fibrous aggregates with a concentric, shelly structure and a rough, nodular or reniform surface (fig. 10); such masses, with their brown colour and markings, possess a certain resemblance to fossil wood, and are known as *wood-tin*. This has, however, nothing to do with fossil wood, but is only a special form of structure, similar to that seen in limonite, malachite, etc.

An example of pseudomorphous cassiterite is shown in fig. 9; here a mixture of cassiterite and quartz has replaced a crystal of orthoclase felspar.

Cassiterite usually occurs in conjunction with ancient granitic rocks, either as small veins traversing the granite and the surrounding rocks or disseminated through the granite itself in the neighbourhood of these veins. Associated minerals are quartz (plate 52, fig. 2), wolframite (plate 37, figs. 8 and 9), fluor-spar (plate 71, fig. 4), topaz, lithia-mica, tourmaline, scheelite, native bismuth, molybdenite, etc. The felspar crystals in the granite near the veins may, as seen in the pseudomorphs mentioned above, be altered into a mixture of quartz, cassiterite, topaz and lithia-mica, and the rock itself may be transformed into a mixture of quartz and mica known as greisen. To account for these associations and alterations it is assumed that, after the injection of the granitic magma, hot vapours arising from the earth's interior or emanating from the magma itself penetrated the mass along numerous fissures, bringing with them the materials for the tin-stone and the associated minerals. This assumption is supported by the experiment of Daubrée, in which be prepared cassiterite artificially from vapours of tin chloride and super-heated water. Since many of the minerals associated with cassiterite contain fluorine, it may be concluded that in nature cassiterite has been formed by the interaction of tin fluoride and water vapour, and that the powerfully acting fluorine compounds have produced the alteration of the granite to greisen. Further support to this theory is given by the fact that the siliceous sinter deposited by the hot spring of Ajer Panas in Selangor contains half a per cent. of tin oxide.

With a mode of occurrence of this kind, cassiterite is found at several places in the Erzgebirge (plate 38, figs. 3, 4, 5, 7 and 8), namely at Altenberg and Ehrenfriedersdorf in Saxony, and at Zinnwald, Graupen and Schlaggenwald in Bohemia; in Cornwall and Devonshire; at La Villeder in the French department of Morbihan (fig. 1 and 6); in the Malay islands of Banka and Billiton and the Malay Peninsula; and in New South Wales and Tasmania. The tin ore occurring in these original deposits is known as *vein-tin*, to distinguish it from the more important stream tin to be mentioned presently.

Original deposits of another type are met with on the Bolivian tableland in the neighbourhood of Oruro and Potosi. Here the veins are not in ancient granitic rocks,

but in newer, acid volcanic rocks of the trachyte and andesite class, and the associated minerals are stannite, wolframite, and ores of silver, copper and bismuth. The fluorine-bearing minerals, fluor-spar, apatite and tourmaline, are here of rare occurrence, and it is only quite recently that their presence has been recognized, whilst topaz has not yet been found. Moreover the cassiterite itself is quite different in appearance to the cassiterite of other localities; crystals of any appreciable size are rare, and the mineral usually forms compact, fine-grained masses, often intimately intermixed with sulphides, and frequently with pseudomorphous impressions of other minerals. The tin ore near the surface in these veins is replaced at greater depths by sulphide ores, and the late Professor A. W. Stelzner considered it probable that the tin was originally present as stannite, which in the upper part of the veins had become altered by atmospheric weathering to the more stable form of tin oxide, in the same way that iron-pyrites gives place to limonite and copper-pyrites to cuprite and limonite. Bolivia is, in fact, noted for the complex sulphide compounds of tin mentioned above (p. 184), several of which have not been found in any other part of the world.

By the denudation of the rocks containing the veins of tin ore, the latter is set free, and, being a very stable compound of high specific gravity, it collects as pebbles in the beds of streams and rivers, and is then found under exactly the same conditions as alluvial gold (p. 76). Stannite, if present in the veins, will be decomposed, and the oxide of tin so formed may be deposited in a concretionary form as wood-tin; this, indeed, explains the more frequent occurrence of wood-tin in alluvial deposits than in veins. Many of the associated minerals in the tin veins will also be decomposed by weathering and their products carried away by running water. The tin ore (cassiterite) of such alluvial deposits is known as *stream-tin*, and is not only much purer and more suitable for smelting than vein-tin, but it is also far more easily mined. Deposits of stream-tin are thus the first to be worked, and even at the present day the bulk of the ore raised consists of stream-tin.

Of the tin-producing countries, the Malay Peninsula (Straits Settlements) is the richest, with a yield of four-sevenths of the total for the whole world. The ore occurs here in veins and especially in alluvial deposits. The somewhat water-worn crystal shown in plate 38, fig. 2, is from Selangor. Many of the richest tin placers have already been exhausted, but, with the present high price of tin, the very widely distributed poorer deposits can be worked at a very considerable profit. There is no immediate prospect of any decline in the production, and when, at some future time, this should happen there still remain the unexploited deposits in the northern states of the peninsula. The richest occurrences lie along a belt extending from the northern border of Malacca through the Federated Malay States and the state of Kedah, and across the Kra Isthmus far into Burma. There is scarcely a valley which does not contain more or less stream-tin. The richness in tin of this region was known long before the Christian era, and the deposits have been worked by the natives and the Chinese from the very earliest times.

Tin ore occurs under very similar conditions also in the Dutch islands of the Malay Archipelago, especially in Banka (known since 1710) and Billiton (since 1852). The tin gravels are worked by the Chinese under the direction of European engineers. Tin ore is also mined in Siam, China and Japan, though in the two latter countries only sufficient for home consumption.

Throughout the whole of Australia and New Zealand deposits of tin ore are widely distributed, and they may be considered as an extension of the Malayan deposits. The mode of occurrence is exactly the same, there being true veins and disseminations in granite and porphyry and in addition extensive alluvial deposits. The latter are not

only of recent date in the beds of the present streams and rivers, but also occur in ancient river beds of Tertiary age, and these are sometimes covered over by ancient flows of basaltic lava. The conditions here are thus exactly the same as with the more ancient gold sands of California which also are protected from destruction by a capping of basaltic lava. One of the richest of Australian deposits is that of Mount Bischoff in the north-western portion of Tasmania, where since the year 1873 both the gravels and the veins have been worked. Other tin fields are situated in the northern part of New South Wales (Emmaville district), in Queensland (Herberton district) and in Western Australia (Greenbushes).

In America, the most important tin-producing country is Bolivia. Here alluvial deposits are of no importance, and it is only during the last twenty years or so that the veins have been worked on a larger scale. In Mexico tin ore is widely distributed, but the production is not of much account. Recently, extensive alluvial deposits have been discovered in Alaska.

In Europe, the only tin-producing district of any importance at the present day is Cornwall, where the rich tin ores have been worked since very early times. The largest vein, the Dolcoath main lode, is $2^1/_4$ miles in length and on it are situated the important mines of Carn Brea, Tincroft, Dolcoath, and Cook's Kitchen. The annual production of ore reached a maximum of 16,759 tons in the year 1871, since when it has steadily declined owing to the great depreciation in the price of tin; more recently, however, with an increase in the price of tin, many of the old mines have been re-opened. The tin-bearing districts in the Erzgebirge between Saxony and Bohemia were mainly exhausted from the fourteenth to the sixteenth centuries, and are now only of scientific interest, though wolframite is still being obtained.

In France, tin ores have been won at various spots in Brittany, principally at Piriac and La Villeder, but the numerous attempts have led to no very lasting results. A zone of tin deposits extents through the Spanish provinces of Zamora, Pontevedra and Orense into the Portuguese province of Traz oz Montes; the ore occurs in veins and gravels and has been won during several centuries. It is indeed probable that the Romans obtained their first supplies of tin from this region. The production of Spanish ore for the year 1897 amounted to 2378 tons, but this ore is poor in tin. In Italy, deposits are known in Tuscany, but the ores are of little value; they are said to have been worked by the Etruscans.

The production of tin during the year 1901 is given in the following table: all other countries taken together do not produce as much as half a per cent. of the total amount.

Straits Settlements	50,352	tons.
Dutch East Indies	19,350	,,
Bolivia	7400	,,
Australia	3076	,,
Cornwall	4700	,,

The average price of a ton (1016 kilograms) of tin in the year 1900 was about £135, while in 1897 it was only half this amount.

The applications of tin are very varied, and in the history of mankind tin is one of the most important of metals. Its early discovery is readily explained by the ease with which the metal may be obtained by smelting from the ore, and the occurrence of the ore as heavy pebbles in river gravels would soon attract attention. The metal obtained from stream-tin has also the advantage of being very pure, whilst that yielded by vein-tin is contaminated by copper, iron and arsenic. Alloyed with

lead or antimony it is largely used for household utensils, table services, toys, organ pipes, medals and plates; of other alloys, bronze (an alloy of tin and copper, p. 113), is the most important. The metal is also largely used for coating the surface of sheets of iron (tin-plate) and for coating copper. When rolled out into thin sheets, we have the well known tin-foil, largely used for packing confectionery and tobacco. Tin-foil amalgamated with mercury is employed as the coating at the back of glass mirrors.

Salts of tin find an application in dyeing, their action being that of a mordant to fix the colouring matter in the fibres of the fabric.

Titanium Compounds.

The three minerals, rutile, anatase and brookite represented on plate 39 are identical in chemical composition, but different in crystalline form and physical characters. They consist of titanium dioxide, TiO_2, which is usually known as titanic acid. Rutile is tetragonal with a prismatic habit, anatase tetragonal with a pyramidal habit, and brookite is rhombic. We have here an excellent example of polymorphism.

Rutile presents many points of interest in the development of its tetragonal crystals, though well-developed simple crystals are by no means common. The crystal shown in plate 39 fig. 1 (like the crystal of cassiterite in text-fig. 147) is bounded by square tetragonal prisms of the first and second orders, and by tetragonal pyramids of the two orders. The smaller pyramidal face to the front of the figure is taken as belonging to the primary pyramid P, with angles of 123° 8′ between its faces; its edges are truncated by the larger faces of the pyramid of the second order $P\infty$. The prism faces to the left and the right falling directly beneath the latter belong to the prism of the second order $\infty P\infty$, while the prism face to the front is of the first order ∞P. The crystals in figs. 2 and 3 show the same forms, but they are represented with the prism and the pyramid of the second order to the front; in figs. 2 and 4 the prism faces are vertically striated and rounded; in figs. 4 and 5 only one of the pyramids is present.

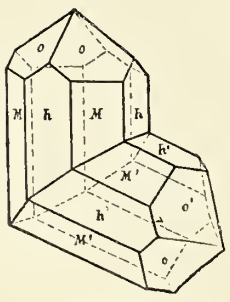

Fig. 149.
Twinned crystal of Rutile.

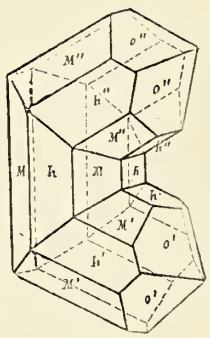

Fig. 150.
Trilling of Rutile.

Twinned crystals of rutile are of much more frequent occurrence. In the twins shown in text-figs. 149 and 150 the faces o are the primary pyramid of the first order, M the prism of the first order, and h the prism of the second order. The twin-plane is a face of the pyramid of the second order $P\infty$; in fig. 149 and in the lower part of fig. 150 the twin-plane is parallel to a face which would truncate the upper left-hand edge of o, while the upper individual of fig. 150 is twinned on the face which would truncate the upper right-hand edge of o. In fig. 150 we thus have the twinning taking place on two faces of pyramid $P\infty$, so that the compound crystal, or trilling, here consists of three individuals; and this twinning on different aces of the same form may be several times repeated. The striated prism planes the two portions are inclined at an angle of 114° 25′, forming a knee-like bend, as is wn in plate 39, fig. 7. In this fig. 7 the twinning is several times repeated on

the same plane, giving rise in the upper portion to a step-like or lamellar structure. In figs. 6, 8, 9 and 10 the twinning is repeated on different planes, and the several individuals (eight in fig. 10) form a closed ring.

Another twin-law met with in rutile is illustrated in fig. 13 and text-fig. 151, the twin-plane here being a face of a steeply inclined pyramid of the second order $3\,P\,\infty$; this is know as the "arrow-head" twin. The prism faces are recognizable by their vertical striations; in fig. 11 the pyramid faces are much rounded and water-worn.

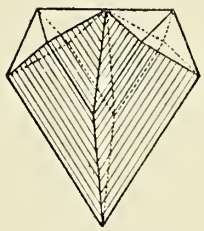

Fig. 151.
Twinned crystal of Rutile.

Other results of twinning in rutile are represented in plate 19, figs. 9 and 10, where, instead of thick prismatic crystals, we have delicate acicular crystals repeatedly twinned together according to one or both of the two twin-laws just mentioned, giving rise to an intricate network. Such network forms of growth in rutile receive the special name *sagenite*, and they are frequently much more delicate than represented in the figures. Sometimes these sagenite webs are found embedded in crystals of quartz (plate 54, fig. 8), while the enclosure of tufts of delicate needles and hairs of rutile are of frequent occurrence (plate 55, fig. 4).

Of the three modifications of titanium dioxide, that which crystallizes as rutile is the most stable, as is shown by the occurrence of crystals of anatase (plate 39, fig. 17) and brookite (plate 19, fig. 13) altered into rutile, but never the reverse alteration. Anatase and brookite when strongly heated are converted into rutile by artificial means. In an alteration of this kind there is no change in chemical composition, and though the crystal preserves its external crystalline form its internal crystalline structure is destroyed; the mass now consists of a confused aggregate of needles of rutile, which on the surface give rise to a moiré-like appearance when viewed in different positions by reflected light (plate 19, fig. 13).

Prismatic crystals of rutile often form regular intergrowths with crystals of haematite, as already described (p. 153), and sometimes the tabular crystals of haematite may be almost completely replaced by an interlacing network of rutile needles arranged at angles of 60^0 (plate 19, figs. 11 and 12).

In its physical characters, rutile also presents several points of interest, especially in its very high refractive index and its strong double refraction. The refractive index for the ordinary ray is 2·6158 and for the extraordinary ray 2·9029, and the difference, 0·2871, is a measure of the double refraction. The refraction is thus greater than for diamond, while the double refraction is stronger than that of calcite; but unfortunately the mineral is never colourless and transparent.

The colour is dark red, passing into brown or black; crystals are opaque or only translucent, but on their smooth faces they possess a brilliant metallic-adamantine lustre: the streak is yellowish-brown. The dark colour of the mineral is due to the presence of iron oxide to the extent of $2^1/_2$ to 14 per cent.; this impurity is not present as enclosed particles, but it is dissolved in the rutile substance, like a salt is dissolved in water. The specific gravity is about 4·2, increasing with the amount of iron to 4·5; the crystal in fig. 5 has a specific gravity of 4·20, and that in fig. 11 the value 4·23. The hardness is $6—6^1/_2$. Crystals possess perfect cleavages parallel to the faces of the two prisms.

Rutile is found in veins and crevices in crystalline rocks (granite and gneiss) often together with rock-crystal, and not infrequently it is actually embedded in the quartz crystals (plate 54, fig. 8 and plate 55, fig. 4); other associated minerals may be anatase, brookite and iron-glance. Under these conditions the mineral is found at several

places in the Alps: for instance, in the Binnenthal in Wallis (plate 39, figs. 2 and 6; plate 19, figs. 11 and 12), Tavetsch in Graubünden (plate 39, fig. 9), Medels Pass in Switzerland (plate 19, figs. 9 and 10); in Norway (plate 39, fig. 1), the Ural Mountains (fig. 8), North America (figs. 3, 7, 10), Brazil (plate 39, fig. 11, and plate 55, fig. 4). The water-worn crystal shown in fig. 11 is from the diamond-bearing sands of Brazil.

In quantities sufficiently large for mining it is met with in Norway, and in a quartz-felspar-rock on the Tye river near Roseland in Nelson Co., Virginia. Besides being employed for the preparation of the little-used compounds of titanium, rutile also finds an application in the manufacture of special kinds of cast-iron and cast-steel. The price per ton varies between 350 and 450 dollars.

Anatase usually crystallizes in the form of acute tetragonal pyramids, which are opaque and dark steel-blue in colour (plate 39, fig. 12). The tips of the crystals are often broken off by a smooth cleavage face parallel to the base, the angle between the pyramid faces and the base being 97° 52′. These crystals are always quite small in size, and only rarely larger than that represented in fig. 12.

Crystals of quite a different habit and appearance are found in the Binnenthal in Switzerland; these are much larger, and are transparent with an Isabel-yellow or yellowish-brown colour (plate 39, figs. 13—15); they are bounded by a profusion of brilliant faces, and in their perfection of development far surpass the crystals of anatase from any other locality. In fig. 13 and 14 the forms present are the prism of the second order and smaller and larger pyramids of the first order; in fig. 15 the prism of the second order, an eight-sided pyramid $P3$ with rough faces of variable size, and a pyramid of the first order $\frac{1}{3}P$. A third habit of anatase is represented by the thick-tabular crystals from Brazil (fig. 16) with an acute pyramid and the base.

In addition to a perfect cleavage parallel to the base, crystals of anatase also possess perfect cleavages parallel to the faces of the acute primary pyramid; the latter are represented in fig. 14 by the two patches of paler colour, due to the reflection of light from cleavage cracks inside the crystal. The refractive index and the double refraction are high, though somewhat less than for rutile; the refractive index for the ordinary ray being 2·535, and for the extraordinary ray 2·496. Corresponding with this high refractive power, the faces of the crystals, when smooth, display a brilliant adamantine lustre; but frequently they are rough and uneven, and are then dull. The colour is steel-blue, yellow to brown, or sometimes reddish-brown. The specific gravity of crystals from the Binnenthal is 3·83.

The crystal shown in fig. 17 is a paramorph of rutile after anatase. These are found in the diamond-bearing sands of Brazil, and are known to the Brazilians as "captivos". With the contact-goniometer the angle between the pyramidal faces was measured as 96°—98°, so that the form is that of the primary pyramid as in fig. 12. The specific gravity of this specimen was determined to be 3·78, but this low value is probably due to the presence of interspaces between the minute rutile prisms of which the paramorph is composed; other specimens of these "captivos" have a specific gravity of 4·02 and 4·06, which more nearly approach the true value for rutile.

Crystals of anatase are found attached to the walls of crevices in crystalline rocks (granite and mica-schist) in the Alps (at Bourg d'Oisans, Tavetsch, Binnenthal), and loose in the diamond-bearing sands in the province of Minas Geraes in Brazil and in the southern Urals. Microscopic crystals are found in many sedimentary rocks, where they owe their origin to the alteration of ilmenite.

Brookite has the same chemical composition as the two preceding minerals, but differs from them in crystalline form and physical characters; it is named after the English mineralogist H. J. Brooke.

In the form of its crystals it sometimes exhibits a certain resemblance to rutile, being bounded by prism and pyramid planes (plate 39, fig. 18); but these crystals are rhombic and the angle between the prism faces is 99° 40′ instead of 90°. The pyramid with horizontal edges above the prism faces shown in fig. 18 is the primary pyramid P; while the pyramid in fig. 19 (e in text-fig. 152) with sloping lower edges has the symbol $P\breve{2}$. The latter combination of the prism ∞P and the pyramid $P\breve{2}$ presents quite the appearance of a hexagonal pyramid. Crystals of this kind are found in Arkansas, and are for this reason known as arkansite.

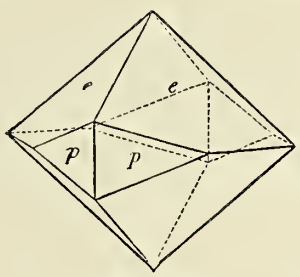

Fig. 152.
Crystal of Brookite (var. Arkansite).

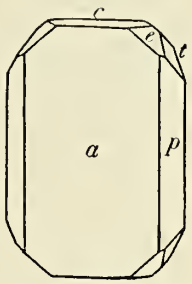

Fig. 153.
Crystal of Brookite.

More usually, however, brookite crystallizes in thin plates, as shown in text-fig. 153 and plate 39, figs. 20—23. In the text-figure the large face a set up vertically in front is one of the two planes of macro-pinacoid $\infty P\breve{\infty}$, p is the vertical prism ∞P, c the base $0P$, e a pyramid $P\breve{2}$, and t a brachy-dome $2P\breve{\infty}$. In the actual crystals the large macro-pinacoid faces are always deeply striated parallel to their intersection with the prism faces. In fig. 21 the basal plane is present as a long narrow face, while in figs. 22 and 23 it is absent. The crystal shown in fig. 20 contains dark enclosures grouped along six lines radiating from the centre of the crystal.

The colour of brookite is brownish-yellow, reddish-brown or black. Black crystals, as in the variety arkansite (plate 39, fig. 19), display a bright metallic lustre. The optical characters of brookite are of special interest, this mineral affording the best example of the phenomenon of crossed dispersion of the optic axes. The observation can be made directly through one of the tabular crystals, providing this is sufficiently transparent. When such a crystal is placed flat on the stage of the polariscope and examined in convergent monochromatic light the usual biaxial interference-figure of a rhombic crystal will be seen. In red or yellow light the plane of the optic axes (i. e. the line joining the centres of two systems of rings) is parallel to the base, and in green or blue light the optic axial plane is perpendicular to the base, while for an intermediate yellow-green colour the interference-figure is uniaxial. In white light the figures corresponding to all the different colours overlap and a very peculiar interference-figure results.

The specific gravity of brookite varies considerably; for the translucent crystal represented in fig. 21 it was determined on the Westphal balance to be 3·94; the crystal in fig. 18 has the value 4·24, while for the crystal of the arkansite variety in fig. 19 it is only 3·77. The hardness is $5^1/_2$—6. As already mentioned, brookite is sometimes altered to rutile (plate 19, fig. 13). Brookite occurs under the same conditions as rutile and often in association with it; thus at Maderaner-thal and Prägratten in the Alps, at Tremadoc in North Wales, and at Magnet Cove in Arkansas; but it occurs sparingly at only a few localities.

TITANATES. — Titanium dioxide, or titanic acid, the different modifications of which we have just considered, occurs also in combination with other elements forming the salts known as titanates. The simplest of these compounds is perovskite, a titanate

of calcium with the chemical formula $CaTiO_3$. Sphene contains silica in addition to these constituents, the formula being $CaTiSiO_5$.

A third mineral belonging to this group is ilmenite, which is essentially a titanate of ferrous iron, $FeTiO_3$. This formula when doubled shows that the mineral may be regarded as a mixture of ferric oxide and titanium sesquioxide: $Fe_2Ti_2O_6 = Fe_2O_3 + Ti_2O_3$; the very close similarity in the crystalline form of ilmenite and haematite favours this view. On the other hand, the mineral frequently contains some magnesium, which can be present only as magnesium titanate, $MgTiO_3$. We must therefore conclude that the iron is also present as titanate, and that it is partly replaced by magnesium, in the same way that iron and magnesium are isomorphous in many other minerals (e. g. olivine). For this reason ilmenite is placed here with the titanates, though in some systems of classification it is placed with the oxides.

In addition to the minerals mentioned above, titanium also occurs in some specimens of magnetite, augite, hornblende, garnet, etc., but only in small amounts. A few other titanium compounds are known, but these being minerals of great rarity need not be considered in this work.

Perovskite occurs as cubic crystals bounded usually by only a few simple forms: the cube (plate 40, figs. 1—4) is the most usual, the rhombic-dodecahedron (fig. 5) and octahedron (fig. 6) being rare. The striations on the faces of the cube are sometimes parallel to only one of the edges, as in iron-pyrites, and it has consequently been asserted that perovskite is pentagonal-hemihedral. In other crystals, however, the striations are parallel to two adjacent cube edges, so that if the mineral be hemihedral it is necessary to assume such crystals as interpenetration twins. In addition to these simple crystals, perovskite is sometimes found as crystals extremely rich in faces, the distribution of which point to holohedral-cubic symmetry. When, however, crystals of perovskite are examined optically it is found that they are doubly refracting, whereas we know that cubic crystals are singly refracting. The true symmetry of the mineral is probably rhombic, and this lower degree of symmetry is completely obscured in the external form by twinning, the crystals being really pseudo-cubic, though in their interfacial angles they do not differ from true cubic crystals. Sometimes the crystals are deeply corroded and hollow.

The colour of perovskite is reddish-brown to black, and pale coloured crystals are extremely rare; the black crystals possess an almost metallic lustre. The specific gravity is about 4, and the hardness 5—6. In addition to calcium and titanium, perovskite almost always contains small amounts of iron. The crystals of octahedral habit from Magnet Cove, Arkansas (fig. 6), however, contain appreciable amounts of rare earths (tantalum, niobium, cerium, yttrium, etc.); but these are perhaps not true perovskite, but more nearly related to the rare mineral dysanalyte.

True perovskite is found embedded in chlorite-schist at the Findelen glacier near Zermatt (plate 40, figs. 1 and 2); attached to the walls of crevices in chlorite-schist at Wildkreuzjoch in the Pfitschthal, Tyrol; embedded in chlorite-schist and limestone in the Nikolaje-Maximilianovskoi and the Eremeyev mines at Achmatovsk, near Zlatoust in the Urals (figs. 3, 4 and 5). The octahedral crystals from Magnet Cove, Arkansas (fig. 6), occur embedded in limestone. Microscopically small cubes of perovskite are present in melilite-basalts.

Titanite, or sphene, is a mineral which, while extremely constant in chemical composition, exhibits wide variations in its external form and habit. The crystals are monoclinic and they vary so much in their development that sometimes one and sometimes another set of faces may be taken as the vertical prism: in fact, different mineralogists

have interpreted the crystals in different ways, the form taken by one author as a vertical prism has been taken by others as a clino-dome or a pyramid. These differences are, however, quite unessential and are of no consequence in this place.

The crystal of tabular habit shown in plate 40, fig. 7, has its forms explained by the text-fig. 154 (the relative position of the two figures is, however, slightly different): the large face x is taken as the ortho-dome $\frac{1}{2}P\bar{\infty}$, the narrow faces at the edges of the crystal as the vertical prism $l = \infty P$, and the small triangular faces as another ortho-dome $y = P\bar{\infty}$ and the basal plane $P = 0P$.

The thick-tabular crystals in figs. 11 and 12 might be interpreted as a combination of a large base with a pyramid and a prism; but giving these crystals the same orientation as text-figs. 154 and 155, the large face belongs to the ortho-dome $y = P\bar{\infty}$, and the faces at the edge to the clino-dome $r = P\grave{\infty}$ and the pyramid $n = \frac{2}{3}P\grave{2}$. The crystal of prismatic habit in fig. 13 is comparable with text-fig. 155, where $n = \frac{2}{3}P\grave{2}$ is a pyramid,

Fig. 154.
Crystal of Sphene.

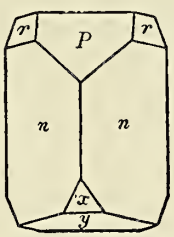

Fig. 155.
Crystal of Sphene.

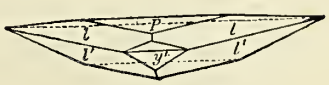

Fig. 156.
Contact-twin of Sphene.

$P = 0P$ is the base, $r = P\grave{\infty}$ a clino-dome, and $x = \frac{1}{2}P\bar{\infty}$ and $y = P\bar{\infty}$ are ortho-domes. In fig. 9 we have an upper and a lower pyramid and an ortho-dome; and in fig. 8 two bright pyramid faces above and the other faces dull and rounded.

Twinned crystals are of frequent occurrence, the twin-plane being the base $P = 0P$, and the crystals either contact-twins (text-fig. 156) or interpenetration-twins. A contact-twin is shown in fig. 10, where the large face to the front is the base and twin-plane; a portion of the second individual behind is visible at the top. The crystals in figs. 15 to 17 are interpenetration-twins.

The variation in colour of sphene is well illustrated in plate 40. Even one and the same crystal may differ in colour in different portions; for example, that in fig. 16 is bright green in the middle but brown at the two ends. The smooth crystal faces display an adamantine to resinous lustre: frequently, however, the crystals are dusted over with chlorite (figs. 7, 14 and 17). There is a rather distinct cleavage parallel to the prism faces. The specific gravity is 3·4—3·6, and the hardness $5^1/_2$.

The interference-figure shown by sphene in convergent polarized light is somewhat remarkable, the hyperbolic brushes being brightly coloured; this is due to the marked difference in magnitude of the angle between the optic axes for light of different colours, the angle for red light being much greater than for blue.

Crystals of sphene are found attached to the walls of crevices in silicate-rocks (gneiss, mica-schist, etc.) at many places in the Alps; for example, at Tavetsch in Graubünden (plate 40, figs. 7, 14, 15 and 16), Dissentis (fig. 17), Zermatt (fig. 8), Maderaner-thal; on the Rothenkopf in the Zillerthal (fig. 18) and at Pfunders in Tyrol; Stubachthal in Salzburg, etc. Crystals are also found together with chlorite and diopside on the walls of crevices in chlorite-schist at Achmatovsk in the Urals (fig. 10).

Larger, embedded crystals are known from the syenite of Arendal in Norway (figs. 13 and 19), and in crystalline limestone at Eganville, Renfrew Co., Ontario. Small

embedded crystals of a yellow or brown colour are widely distributed in syenite, phonolite, trachyte and allied rocks.

Sphene, when quite transparent and of a good colour, is sometimes employed as a precious stone, but owing to its low degree of hardness it soon shows signs of wear.

Ilmenite, or titaniferous iron-ore. A few remarks concerning the chemical composition of this mineral have already been given (p. 192). In its crystalline form it is very similar to haematite. The thick-tabular crystals (plate 40, fig. 20, and text-fig. 157) are bounded by the large basal pinacoid $o = 0P$ and two rhombohedra, one of which (R) truncates the edges of the other (d); taking the former to be the primary rhombohedron R, the second, being the next steeper negative rhombohedron, is $d = -2R$. In addition, there are faces (n) truncating the alternate edges between R and d, this form being a rhombohedron of the third order, and the symmetry of the crystals is consequently rhombohedral-tetartohedral, as in dioptase (p. 112). In haematite, on the other hand, these faces truncate all the edges between R and d, and the complete form is here a hexagonal pyramid. Crystals of ilmenite and especially crystalline masses are frequently penetrated by twin-lamellae parallel to the three faces of the primary rhombohedron; these give rise to three sets of striations at angles of 60° on the basal plane (fig. 21).

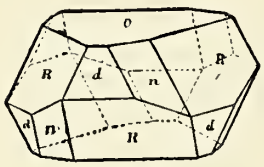

Fig. 157.
Crystal of Ilmenite.

Ilmenite is black in colour with a metallic lustre, and is sometimes slightly magnetic. It is slowly dissolved by hot hydrochloric acid, and in the microcosmic salt bead gives a blood-red colour owing to the presence of titanium. The mineral occurs embedded in igneous rocks (gabbro, diabase, dolerite) and under these conditions is very widely distributed. Fine crystals are found at Miask in the Ilmen Mountains, Urals (plate 40, fig. 20), from which locality the mineral derives its name. Much larger crystals are met with at Kragerö and Arendal in Norway.

The so-called "iron-roses", described under haematite (p. 152) as occurring in crevices of the crystalline rocks of the Alps, are in part to be placed under ilmenite, when they contain a considerable amount of titanium dioxide. According to the predominance of the ferric oxide (Fe_2O_3) or of the ferrous titanate ($FeTiO_3$), these crystals may be considered as haematite containing admixed ferrous titanate or as ilmenite with admixed ferric oxide. It is possible that in some cases the titanium dioxide may be merely due to the inclusion of microscopic needles of rutile.

Massive ilmenite occurs at several places in Sweden and Norway and in Canada and the United States as a magmatic separation from gabbro, and sometimes in sufficient quantity for mining. Water-worn grains of ilmenite (titaniferous iron-sand) are found in the sands of certain rivers, often together with gold and precious stones. Rounded grains of magnetite rich in titanium dioxide are found in certain basalts (e. g. at Unkel on the Rhine); this has an uneven shining fracture and is readily distinguished from ilmenite by its strong magnetic character.

Ilmenite is employed, like rutile, for adding to certani kinds of steel, but its use is only limited.

The Precious Stones and related Minerals.*)

Precious Stones. The minerals included under this term are distinguished from others by the possession of certain special characters. They have a high degree of hardness, exceeding that of most other substances, which protects them from injury. They should be transparent and colourless or beautifully coloured; if cloudy or opaque, they should have a bright colour, as in turquoise, or some special optical effects, as in precious opal, cat's-eye and star-sapphire. Further, they must not be of widely distributed occurrence or found in very large masses. Minerals in which these characters are very prominent are the most valuable, as for example, diamond and ruby; while others in which they are less marked are of correspondingly smaller value, as in quartz and the other so-called semi-precious stones. No sharp line can, however, be drawn between precious stones and semi-precious stones, or between these and other minerals.

From the point of view of the practical jeweller, all minerals which are cut and polished for personal wear or for purposes of decoration may be regarded as precious stones; but the application of the term depends largely on the prevailing fashions; for instance, in recent years many cloudy and opaque stones, if of good colour, have been much worn. To the mineralogist, on the other hand, these special characters are of only secondary consideration, those of primary importance being the essential characters, such as chemical composition, crystalline form and physical properties, which serve to define the mineral species. The colour, on which the value of precious stones largely depends, is, as a rule, quite an accidental character of minerals, and different specimens of the same mineral species may be of very different colours. For instance, the mineral corundum when clear and of a rich red colour is more valued as a gem than diamond, while when grey and opaque it is if no value whatever as a precious stone. While the differently coloured varieties of corundum are regarded by the jeweller as separate gem-stones, each with its distinctive name, to the mineralogist they are identical, since they possess the same essential characters.

In this section we shall therefore describe those species of minerals of which certain specimens are suitable for use as gem-stones, describing at the same time also those varieties which are unsuitable for this purpose. We shall further, as a matter of convenience, include certain other minerals which are closely related to these. For instance, the description of diamond will be followed by that of graphite, since both of these minerals consist of the chemical element carbon; to that of beryl (including emerald) we shall append those of other minerals which contain beryllium. With the description of the numerous gem-varieties of the semi-precious stone quartz, we shall include an account of the other varieties, and so pass on to the next section dealing with rock-forming minerals, in which quartz might more properly be included. The minerals which we have thus more or less arbitrarily grouped together in this section will be described mainly from the mineralogical point of view as species, but mention will be made of their application as precious stones and of many of the points of interest in this connection.

Forms of cutting. In their natural form as crystals or as water-worn pebbles, precious stones do not display to advantage those characters on which their application

*) Together with other works, use has been made of Professor Max Bauer's "Edelsteinkunde" (Leipzig, 1896), translated into English by L. J. Spencer, "Precious Stones" (London, 1904).

as gems depends; nor are they in a form suitable for wearing as personal ornaments. In order to bring out these characters, it is necessary to cut the stones into special shapes, and during this process a large proportion of the valuable material is sacrificed.

The actual form of cutting adopted must bear some relation to the optical characters of the stone, as well as to the natural form, such as the relative thickness and width, of the fragments. As a rule also, different forms are adopted for colourless and for coloured stones.

A colourless stone must be so cut that it displays to the full its strong refractive power and the prismatic play of colours; the form of cutting most suited for this purpose is the *brilliant* (figs. 158, a—c). The ground-form of the brilliant may be regarded

Fig. 158 a.

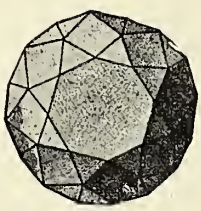

Fig. 158 b.

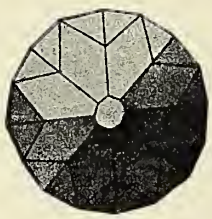

Fig. 158 c.

Brilliant form of cutting. a) viewed from the side, b) from above, c) from below. (After M. Bauer.)

as an octahedron with its upper corner cut off by a large facet, and its lower corner replaced by a small facet; the large facet is known as the table (fig. 158b), and the small facet as the culet (fig. 158c). Between the girdle, or margin, of the stone and each of these facets a number of other small facets are symmetrically arranged. A brilliant is mounted in an open, or claw, setting, also known as *à jour* setting, with the large table facet to the outside and the small culet below. Rays of light falling on the front of the brilliant are able to enter the stone, but they are unable to pass out at the back; they are totally reflected (p. 58) by the facets at the back, and thrown out again from the front, thus giving a brilliant reflection like that from polished silver.

With brilliants of the same size and form, but of different minerals, the amount of light so reflected back by the stone will depend on the index of refraction of the material; the higher this index, the more the light will be reflected, and the brighter and more lustrous will be the stone. The refractive index of air being unity, the values for some other substances are: water 1·33, quartz 1·55, topaz 1·62, corundum 1·76, zircon 1·97, and diamond 2·41. In quartz, all the rays of light which strike the surface at a less angle than 40° 10′ with the normal to the surface are able to pass out of the stone into air; but in diamond, with its much higher index of refraction, this angle is reduced to 24° 30′, so that much less light is able to pass out into air and more is totally reflected. A brilliant cut in quartz therefore shows but a poor reflection, as compared with the blaze of light from a diamond cut in the same form.

In addition to this reflection of light by the brilliant, there is also a splitting up of white light into it coloured components. The facets at the edges, through which the light enters and emerges, act as prisms, and prismatic colours are produced. Here again, diamond, owing to its very high dispersive power, surpasses all other colourless gems; the brilliant flashes of prismatic colours, red, green, blue, etc., often referred to as the "fire" of a stone, being especially characteristic of diamond.

For a brilliant to display these qualities to the best advantage, the facets must be inclined at certain angles, or, in other words, there must be a definite relation between the height and the breadth of the cut stone. In diamond, the height of the

portion above the girdle must be one-third, and that of the portion below two-thirds, of the total height of the stone; and the diameter of the table facet must be five-ninths, and of the culet one-ninth, of the diameter of the girdle. In other colourless stones (e. g. topaz) these proportions will be different; and frequently the form of cutting may be quite different, the upper portion only being cut in the brilliant form while the lower portion may be given the star-cut. Since diamond is most frequently cut in the brilliant form, it is often customary to speak of diamonds so cut simply as brilliants; and conversely by the term brilliant a diamond is often understood. This may lead to some confusion, if, for instance, a colourless topaz cut in the brilliant form is sold as a brilliant. It must not be forgotten by a purchaser that the term can strictly be applied only to the form of cutting and not to the mineral.

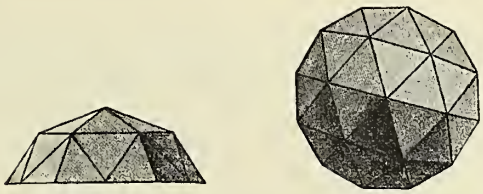

Fig. 159 a. Fig. 159 b.

Rosette. a) viewed from the side, b) from above.

The *rosette* or *rose-cut* (fig. 159 a and b) is another form of cutting frequently adopted for the diamond, especially for flatter pieces of rough material, the cutting of which in the brilliant form would involve a considerable loss of material. Other colourless stones are also, but less frequently, cut in this form. Here there is a broad, flat face beneath, from which rises a low pyramid bounded by a number of small facets. The brilliancy and play of colours displayed by a diamond cut in this form are much less than with the brilliant form, and the value is correspondingly less. The brilliancy may be increased by placing a silver foil beneath the large flat face and hidden in the setting.

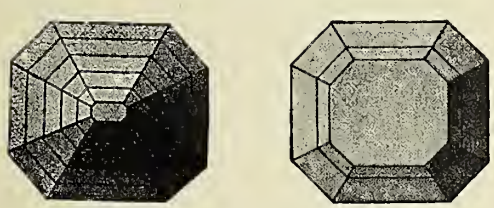

Fig. 160 a. Fig. 160 b.

Step-cut. a) viewed from below, b) from above.

Coloured stones are cut in a form which will display the colour to the best advantage, the most usual being the *step-cut* or trap-cut (fig. 160 a and b). Or there may be a mixed form of cutting, the upper portion of the stone being given the brilliant-cut and the lower portion the step-cut or the star-cut. For stones possessing a deep colour the form is made flatter than when the colour is paler. Those stones which differ in their colour or in the intensity of the colour in different directions, that is dichroic stones, must be cut in a certain direction if they are to show to the best advantage.

Opaque and translucent stones, the beauty of which depends solely on the colour or play of colours, are cut *en cabochon*, that is, with a rounded convex surface. This is the earliest form of cutting, having been used by the ancients for coloured stones, while at the present day it is adopted for turquoise, precious opal, star-sapphire, cat's-eye, etc.

Some precious and semi-precious stones, especially those with a uniform internal structure or with differently coloured bands are employed for engraving as *gems*. Two kinds of gems are to be distinguished; when the engraved figure is in relief we have the *cameo*, and when it is sunk below the surface the gem is called an *intaglio*.

The **process of cutting** and polishing precious stones varies somewhat according to the character and value of the material.

In the case of the valuable and extremely hard diamond no more material is removed than is quite necessary for the production of a finished stone, which should be as large as the rough material will allow, and at the same time free from flaws. The superfluous material is not removed by the usual process of grinding, since this

would be an extremely lengthy operation, and furthermore this material would be lost. Advantage is taken of the perfect cleavage parallel to the octahedral faces of diamond, rough stones of unsuitable shape for cutting being first reduced to approximately the required form by cleaving. The larger facets of the brilliant form are then roughly shaped by the operation known as bruting or greying, which consists in vigorously rubbing two diamonds together, the stones being fixed to the ends of short sticks, or handles, with a hard cement or an easily fusible alloy. The facets are finished by grinding, as with other precious stones, but here the abrasive material must be the diamond powder itself.

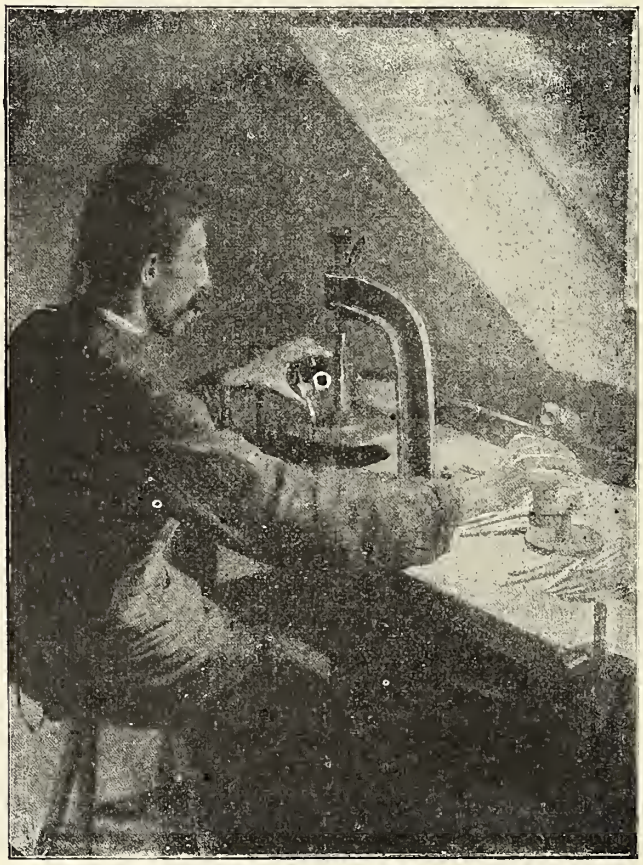

Fig. 161.
Gem-cutter at work.

The other precious stones, if in fragments of unsuitable shape, must be broken, or cut with the slitting disc — a thin disc of soft iron charged on its edge with diamond powder. For grinding, the stone is cemented to the end of a short holder or "dop", which is held in a clamp and pressed against the grinding disc. This is made of hard bronze or steel, and the grinding material consists of diamond powder in olive-oil for the harder stones, or corundum (emery) for the softer. In recent years the abrasive material almost exclusively used for all stones except diamond is carborundum, which is a compound of silicon and carbon produced artificially in the electric furnace.

In the accompanying illustration (fig. 161) the gem-cutter with his left hand presses the stone on the revolving disc, while with his right hand he regulates the speed of the disc, which is driven by water, electrical, or other power. On the table to the right are several of the short sticks to the ends of which the stones are cemented. In the operation of diamond grinding, the clamps are weighted with masses of lead, and several are placed on the disc at the same time, the grinding here proceeding much more slowly and the worker has time to attend to more than one stone. When one facet has been ground down to its proper shape, the stone has to be loosened from the cement and cemented again in another position. And when all the facets have been shaped by grinding with carborundum, they have then to be polished. This is done on discs of bronze or wooden cylinders with tripolite, putty powder or caput mortuum. A wooden cylinder used for polishing is to be seen on the left in fig. 162.

Larger stones such as agate and chalcedony are not cut in this manner, since the worker cannot press the stone against the disc with sufficient force and the disc

will not withstand the pressure. These stones are ground against the edge of grindstones made of hard sandstone, which rotate on a horizontal axis and are kept moistened with water (fig. 162). The workman lies in a hollow bench, called a cuirass, and, having his feet against a bar fixed to the floor, he is able to press the agate firmly against the revolving grindstone. A special abrasive material is not employed, the grinding action of the grindstone being alone sufficient. For producing rounded surfaces the edge of the grindstone is grooved. After being roughly ground in this manner, the agates are polished on the wooden cylinders.

Such an agate-grinding workshop is shown in fig. 162. The hollowed out form of the cuirass is to be seen at the fifth place, which is vacant. The man on the left

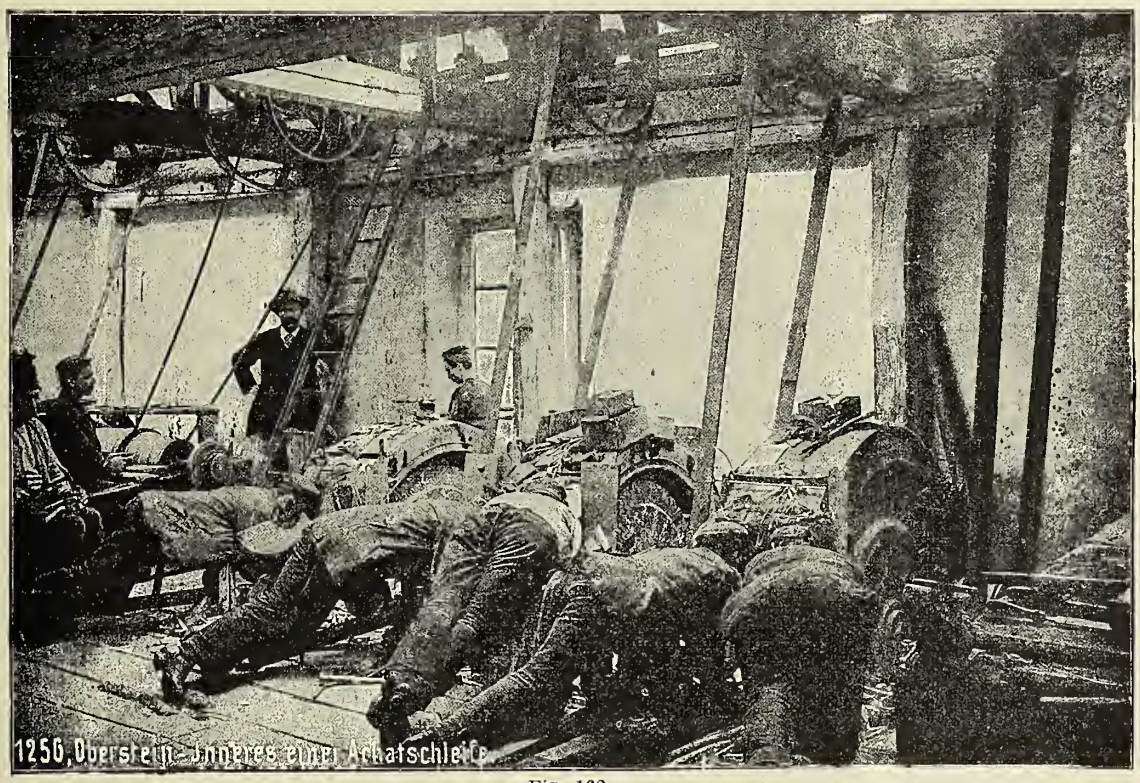

Fig. 162.
Agate grinding at Oberstein, Germany.

trims the stones with a hammer preparatory to grinding, and the boy before the wooden cylinder gives them their final polish. The man by the window in the background is cutting slices of chalcedony with a slitting disc charged with diamond powder.

Although the position of the worker appears to be inconvenient, recent attempts to introduce improvements with a sitting posture have not met with success; in the reclining position the worker is able to exert a greater pressure and is better able to watch the progress of his work.

The operation of boring spheres of agate to be worn as beads is still performed by the same primitive method that has been in use since early times. A steel point charged with diamond powder and held in a wooden cylinder is pressed by a lever against the sphere, and is caused to rotate by a to and fro movement of a bow with a string passing round the cylinder. With such a simple contrivance (fig. 163) the agate borer is able to perform his work at home. Much the same kind of apparatus was

figured 130 years ago by Collini in his Diary of Travels, in which are recorded a variety of mineralogical observations, especially relating to agate and its working. And a figure given by Furtwängler in "Die antiken Gemmen" (vol. III, p. 399) suggests that a very similar form of apparatus was used by the ancient gem-cutters.

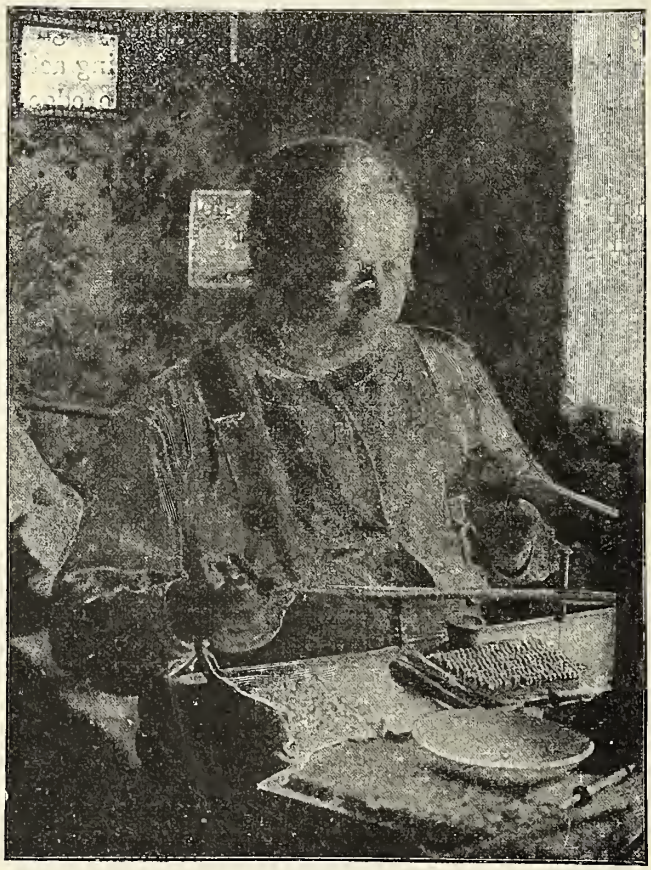

Fig. 163.
Agate borer.

The engraving of gems, seals and initials is an art requiring a considerable amount of skill. At the present time it is performed with small steel discs of various sizes, which are charged with diamond powder and oil and made to rotate rapidly about a horizontal axis (fig. 164).

The **unit of weight** adopted for precious stones has long been the *carat*. This is unfortunately not a fixed and definite unit of weight, but varies at the different centres of exchange. The average value of a carat is 205 milligrams, but different carats vary by as much as 18 milligrams. It would be an advantage if the value of a carat were universally accepted as 200 milligrams, that is one-fifth of a gram. Another curious usage in connection with this unit of weight is that the fractions are one-eighth, one-sixteenth, etc.

The **determination** of precious stones and the distinguishing of one kind of stone from another is in certain cases a matter of some difficulty, for in a faceted stone the external crystalline form has been obliterated and chemical tests involving the destruction of the material are not permissible. Colour, lustre and hardness afford some guide; to the lapidary an indication of the hardness of a stone is given by the time required to grind the facets. The specific gravity (p. 53), which may be determined by means of the Westphal's balance or with heavy liquids, will usually give a clue as to the identity of a doubtful stone, and this may be confirmed by an optical examination with the dichroscope (p. 62) and polariscope (p. 60). The determination of the refractive indices of the stone is also of great assistance, and this method has the advantage that the stone need not be taken out of its mount. Jewellers with a long experience are usually able to identify a stone at sight, but the only safe method in case of any doubt is to determine quantitatively some of the physical constants.

Counterfeiting of precious stones. Precious stones are natural products, and when we purchase one we take it for granted that the stone is a natural mineral. Artificial products do not possess the same charm, nor are they of equal value. The same is the case with wine; an artificial wine may closely approach a natural wine in composition and flavour, but it would be rejected by an expert. Up to the present time, only few precious

stones have been made artificially in the laboratory of the requisite size and quality to pass as gems. The largest amount of success has been met with in the manufacture of ruby. These stones possess the same chemical composition, crystalline structure and physical characters as the natural ruby, and in their external appearance they are also identical; their only difference is that of origin. The artificial stones can, however, be recognized under the microscope, for they contain small, round air bubbles which are not present in the natural stones. Further, they are often more brittle, and their value is much less. Diamond has also been prepared artificially, but the crystals obtained are not sufficiently large and clear to be of use as gems.

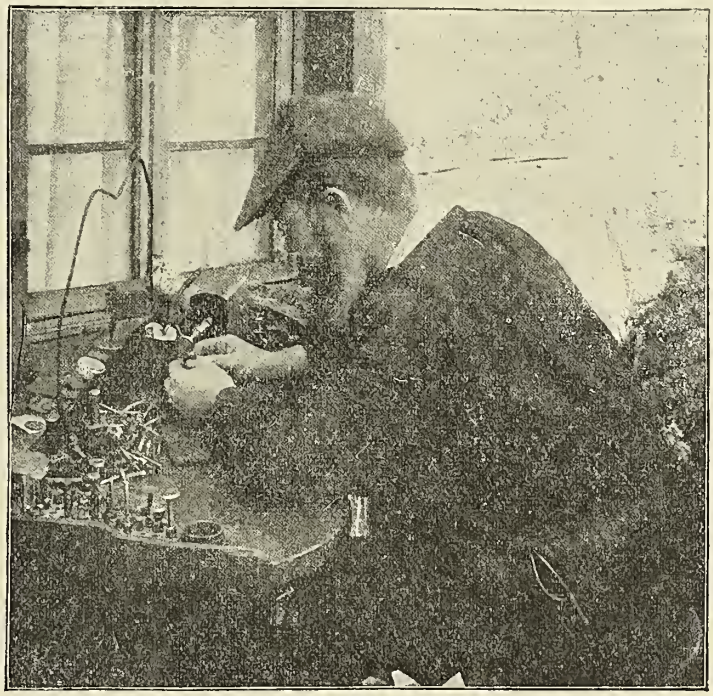

Fig. 164.
Stone engraver.

Deception is practised by making only the upper portion of a faceted gem of a genuine precious stone, the lower portion, beneath the setting, being of glass of the same colour as the stone, and the two portions are neatly cemented together to form what is known as a *doublet*. Sometimes both the upper and lower portions, which are cemented together, consist of genuine stones, and by this means a larger and apparently more valuable stone is formed out of two smaller ones.

Glass imitations are the crudest and at the same time the earliest employed substitutes for precious stones. The glass used for this purpose is known as paste or strass; it is a highly refractive glass containing lead, and is suitably coloured by the addition of various metallic oxides. These imitations are sometimes very deceptive, but they can always be detected by their softness. When worn in jewellery their edges soon become rubbed and chipped, and they can readily be scratched with a knife. Glass being a much worse conductor of heat than crystallized gem-stones, these imitations feel warmer to the hand than genuine stones: for the same reason, moisture from the breath will remain on a glass imitation for a longer time than on a precious stone. The amorphous opal behaves in this respect like glass, while amber feels warmer than glass.

The artificial colouring of precious stones can in certain cases be performed with advantage. For example, yellow topaz when heated acquires a beautiful rose-red colour, and is then sold as rose-topaz or as burnt topaz. The common practice of colouring agates by artificial means is not done for purposes of deception, except, for instance, when a green coloured chalcedony is passed off as chrysoprase or jadeite. The coating of a yellowish diamond with a thin film of violet colouring matter, thereby giving the stone a white appearance, is a deception of the worst kind. Sometimes a stone when

decolourized may be passed off as a stone of greater value, for instance when tiger-eye is sold as cat's-eye.

The **terminology** used by jewellers for precious stones is not only confusing, but also gives many opportunities for deception. Since the colour of gems is of prime importance, different minerals if of the same colour are often known by the same name, and these may be of widely different value. Thus the most valuable of gem-stones is the ruby, a red variety of the mineral corundum, but many of the stones sold as ruby are not true ruby, but red spinel, garnet, topaz or tourmaline. Although these red stones are distinguished from one another by certain prefixes, there still remains a confusion in terms: thus to the jeweller the true ruby is known as "oriental ruby", red spinel as "balas ruby", red garnet as "Cape ruby". Or again, yellow transparent stones may be known as topaz, but the "oriental topaz" is yellow corundum, whilst" occidental topaz" or "Spanish topaz" is quartz. It would be an advantage if the dealers in gems could be prevailed upon to use only mineralogical names for the stones, and these are now being adopted more and more by the larger firms; but the fault lies largely with the public, who would buy a stone under the name of ruby rather than one called spinel.

Historical.*) Like the precious metals, the precious stones have been highly prized since the earliest times. Originally they attracted attention by reason of their colour and lustre, and they were no doubt worn in the condition in which they were found. But even in very early times such stones were ground down into forms suited for specific purposes. They were worn as amulets, and a figure of some deity engraved on them in order to increase their charm: stones so cut were used as seals.

Even at the time of the ancient Babylonians, 4000 B. C., the glyptic art of engraving hard stones had reached a high state of development. The most ancient gems have the form of a pierced cylinder, and, being used for seals, their surface is deeply engraved with figures. Fig. 1 of plate 40a represents the impression made by rolling one of these Babylonian *cylinder-seals* on a plastic surface: as a rule, the figure is repeated twice around each cylinder. The material of which they are usually made is blood-stone; but other stones were also engraved, such as marble, lapis-lazuli, jasper, porphyry, serpentine and rock-crystal, and in later times also amethyst, chalcedony, sard and carnelian. The gems of the earlier period were engraved by hand, as shown by the angularity of the cuts; but those of the later period were engraved with a wheel, the cuts here being more rounded and all the lines have a round ending. The engraving wheel was caused to rotate by a string and bow held in the hand, and it is possible that later the treadle was used. The simple string and bow is used even to the present day for boring precious stones, though no longer for cutting (p. 199).

The art of engraving stones passed from the Babylonians to the ancient Egyptians, whose earliest gems likewise have the cylindrical form. This was soon replaced by the *scarab*, an oval-shaped gem with the form of the sacred beetle (fig. 3, plate 40a), which was later adopted by the Greeks and the ancient Etruscans. The figure of the beetle came to be omitted, though the general shape remained, and the name scarab was retained for oval gems on which various subjects were engraved. Most of the Egyptian scarabs were cut in a soft, blue or bluish-green material resembling faience, which is usually known as Egyptian porcelain; some in a dark blue, transparent glass; whilst seals in the harder precious stones are rare. In recent years many forgeries of the beetle-shaped scarabs have been made.

*) Much of the matter here given has been taken from Adolf Furtwängler's work in three volumes on "Die antiken Gemmen", a work which from the excellence of its text and illustrations may be strongly recommended to gem-cutters.

In the earliest Grecian times of the Mycenaean period, cut stones were worn as ornaments, talismans and amulets, but they were not used as seals. Corresponding with this use, the stones were given a lenticular or orbicular shape, and were pierced, the surface being either smooth or engraved. Floral forms of ornamentation first came into use at that period. In the early Mycenaean period the material used for engraving was mainly the very soft stone steatite, which was worked by hand; but all later and better work was engraved with a wheel in harder stones. In the ruins of the city of Mycenae the work-room of a gem-cutter has been discovered by Tsundas; in a house of the acropolis he found a stock of unworked stones such as were employed for gems, namely chalcedony, agate, rock-crystal, and others; and in another room an unfinished lenticular agate which had been left unbored and without engraving.

In the ruins of ancient Troy of the first and second settlements, which date back to a period even earlier than the Mycenaean, numerous beads and discs of carnelian, lapis-lazuli and amber, and tops of columns and lenses of rock-crystal have been found. The tops of the columns are hemispherical in form with a hole for the column and a small hole at the side for a pin to fix the same.

During the period following the Mycenaean there was a decline in culture and art, and soft stones were carved by hand with but little taste. Not until the end of the seventh century before Christ was the engraving, by means of the wheel, of harder stones, such as carnelian, chalcedony and quartz, again attempted. And it was not until the time of Alexander the Great that the art had again reached the high level at which it once stood in Mycenae. Up till then the designs were sunk into the stone, but now the cameo with a raised design began to be used. The most artistic and perfect of all cameos were cut in Alexandria at the time of Ptolemy. Use now began to be made of the different layers of banded stones. By the Grecian glyptic artists banded stones were so cut that the bands crossed obliquely over the face of the seal; but the cameos were so cut that the bands would be parallel to the face of the stone. The difference in colour and thickness of the several bands afforded the artist an opportunity of exercising his skill in the utilization of these features. The most perfect example of this Alexandrian art which is still preserved is the "Tazza Farnese" cameo. Two other famous stones are the so-called Ptolemy cameos, one of which is represented in plate 40a, fig. 4. These works of art mark the highest point ever reached in the engraving of cameos, and work of the same perfection has never since been achieved.

At the same period the transparent and harder precious stones possessing a beautiful colour and brilliant lustre were also employed. These came mainly from India at the time of its invasion by Alexander. A favourite stone was the hyacinth (identical with our hessonite), and next to this the Syrian garnet: beryl and topaz also came more into use. These harder coloured stones were ground down to a rounded convex surface, and the darker coloured Syrian garnet was made concave on the under side. They were worn as jewellery, especially in ear-rings, necklaces, and golden buckles. According to Strabo, precious stones were used in India for the ornamentation of metal tables, thrones, goblets and washing vessels. And it was from the Orient that the custom of decorating vessels with coloured stones came to the courts of the successors of Alexander the Great, and thence to Rome. In the time of the Roman emperors, stones cut with a rounded surface were used in luxurious profusion for the decoration of garments, shoes, vessels, weapons, chariots and ceremonial articles of all kinds. Constantine the Great bedecked his crown with jewels, and Julius Caesar appeared in the theatre with a wreath of gold and gems. This lavish use of precious stones was passed on to the middle ages — reliquaries, chalices, book-covers and

other articles for religious ceremonies being ornamented with coloured stones cut with a rounded form.

With the decline of power in Greece and Alexandria, the Greek gem-cutters found occupation in Rome; their technical knowledge was developed to the utmost, and resulted in the production of the valuable works of art which have come down to us, more particularly from the time of Augustus. A small cameo of this period is represented in plate 40 a, fig. 5; the most perfect cameo belonging to the same period is the famous "Gemma Augustea" now in Vienna, a representation and description of which is given on plate 58 a. The smaller cameos served as jewels, and masks cut in stone were worn by the Roman officers like the orders of the present day.

The cutting of cameos in higher and still higher relief led, in Roman times, to the complete disappearance of the background, the resulting figure being usually a bust (plate 40a, figs. 6 *a* and *b*). In later Roman times, about the second century before Christ, the glyptic art began to lose favour and to decline. But as the art declined, the greater became the belief in the magic qualities of the stones; little value was attached to the artistic workmanship so long as some mystical symbol was engraved on the stone. This was the case with the abraxas gems, which in the first century of the Christian era were worked in Alexandria and widely distributed as amulets. On many of them was engraved the mystical word abraxas, from the Greek letters $\alpha = 1$, $\beta = 2$, $\rho = 100$, $\alpha = 1$, $\xi = 60$, $\alpha = 1$, $\sigma = 200$, the numerical value of which totals 365, and this, being the number of days in the year, was regarded as a holy number.

The Renaissance brought with it a revival of the gem-cutting industry, but neither the workers of that period nor of the present ever attained to the artistic merit and technical finish of the ancients. At the present day the cutting or grinding of gems, rather than their engraving, has reached a high stage of development.

The cutting of stones with facets was unknown to the ancients, but coloured precious stones have been cut *en cabochon* ever since the time of Alexander the Great. The *faceting* of stones is said to have been first practised in the thirteenth century, but it was not until the middle of the seventeenth century that the most perfect form, the brilliant, was devised by Cardinal Mazarin.

The cutting of facets on a stone is more of the nature of a craft than an art. Although an exact knowledge of the characters of stones is required to produce a good result, this depends largely on the running of the machine and the care of the worker rather than on any artistic qualities he may possess. In a well-cut brilliant we look for the correct proportions of height and breadth, we prize it according to the brilliancy of its fire, the purity of its water, and its size, but it cannot be accounted a work of art. On the other hand, an engraved gem, although cut in a stone with little intrinsic beauty, appeals to the imagination as a work of art, and as a document of the history of human culture it is of the greatest significance. A Ptolemaic cameo, for instance, possesses a far deeper interest and a higher value than the largest diamond.

*Curative charms of precious stones, and other superstitions.**) — There can be no doubt but that precious stones were originally worn and valued as ornaments. As they passed from one generation to another without any deterioration in their beauty and freshness they gradually came to be regarded as amulets by their possessors. The stone itself by reason of its imperishable nature came to be regarded as conferring on its wearer the same immunity from disease and the attack of evil spirits. In later

*) H. Fühner, "Lithotherapie" (Berlin, 1902).

times the engraving of mystical symbols, such as the word abraxas, was believed to increase the magic power of the stone; and stones were then worn as health-bringing amulets rather than for any decorative purpose.

Different stones are supposed to possess powers of differents kinds, to bring certain virtues or repel certain evils. It is significant that the precious opal, a soft stone with an uncertain and changing play of colours, should very generally be regarded as unlucky, and will not be worn by many persons (for instance, the Empress Eugénie). On the other hand, it is said that the possessor of an opal will never be troubled with diseases of the eye. Again, the play of colours from an opal is supposed so to dazzle bystanders that the wearer becomes invisible; and on this account the opal is in favour with thieves. Amethyst is said to be a protection against drunkenness, to bring pleasant dreams, and good luck to the wearer. Beryl should be worn as a protection against soreness of the eyes, and to foster love. A beryl engraved as a scarab (plate 40a, fig. 3) brings with it the power of divination and oratory, providing the wearer leads a chaste life. The emerald brings liberty to the captured, and protects the mariner from violent storms. The chrysolite is regarded as a prophylactic against fevers, gastric pains, and kidney diseases. Red jasper is considered to be a styptic, while sapphire or lapis-lazuli is a cure for scorpion stings.

If precious stones confer all these wonderful benefits by simple contact with the body of the wearer, their action when powdered and taken internally must indeed be marvellous. In former times they were therefore believed to be of medicinal value, and it is probable that many fine stones were sacrificed to this superstition. This use of precious stones was brought into Europe by the Arabs, and held ground for many centuries, until with the advance of chemical knowledge it was held up to ridicule. Powdered blood-stone was used to stop bleeding and to cure watery and blood-shot eyes: this use being based on the belief that blood-stone was formed from dried-up blood.

In catholic countries stones are worn as amulets even to the present day; this being especially the case with chiastolite, a stone which in transverse section shows a black cross on a greyish ground. But the belief in the curative and protective properties of precious stones has long ago died out.

Diamond.

Amongst precious stones diamond is the best known and the one most extensively used in costly jewellery; it is distinguished from all others by its great hardness, high refractive power, brilliant fire, and its rarity.

The *hardness* of diamond is greater than that of all known substances, and is not even approached in this respect by any other mineral; it is 140 times harder than corundum, which after diamond is the next hardest mineral, and a thousand times harder than quartz (see p. 52). Owing to this great hardness a cut diamond never shows any signs of wear. That diamond is the hardest of all substances was known to the ancients, and Pliny wrote: "When struck upon an anvil it returns the blow and both hammer and anvil are shattered; it is also resistant to fire and cannot be made to glow. Its resistance to steel and fire may, however, be overcome by goat's blood, but only when this is warm and freshly bled, and only after several blows, the anvil and hammer being also always broken." That this was merely fable must have been recognized by Pliny, for a little farther on he says that diamond may be broken by

blows into small splinters, which are used by the gem-cutters for embedding in iron and so boring hard stones with ease. Nevertheless, this fable of the indestructibility of the diamond — from which indeed its name, adamas, is derived — passed through the whole of the middle ages; it being also mentioned in the writings of that period that the power of the diamond is overcome by the use of goat's blood, especially if the goat has previously drunk wine or eaten parsley. As a matter of fact, diamond, in spite of its great hardness, can be readily pulverized, since it is a very brittle substance and further possesses perfect cleavages parallel to the faces of the octahedron. The brittleness of some crystals is indeed so great, that they of their own accord fly to pieces, like a quickly cooled and unannealed glass. Use is made of this brittleness, or frangibility, of the diamond in the preparation of diamond powder; this being largely used by the lapidary and gem-cutter, and it is the only material with which diamonds can be cut. Use is also made of the property of cleavage in reducing the stones to a more suitable shape preparatory to cutting. As already remarked, the ground-form of the brilliant is an octahedron, so that the octahedral cleavage enables this form to be readily obtained.

The brilliant lustre, or *fire*, and the play of prismatic colours are, to the eye, the most striking features of the diamond, but as already remarked they are only obvious when the stone is cut in a suitable form; they depend on the high refractive and dispersive powers of the substance. The refractive power is expressed by the following refractive indices (μ) for differently coloured rays of light, while the difference between these numbers is a measure of the dispersion: —

For	red	light	(B	line	of	the	spectrum),	$\mu = 2{\cdot}40735$
,,	yellow	,,	(D	,,	,,	,,	,,	$\mu = 2{\cdot}41734$
,,	green	,,	(E	,,	,,	,,	,,	$\mu = 2{\cdot}42694$
,,	violet	,,	(H	,,	,,	,,	,,	$\mu = 2{\cdot}46476$.

The character of the lustre displayed by the surface of diamond, even when in the rough condition, is of a special kind and is known as adamantine lustre; on rough surfaces this may approach to metallic in character, and some rough diamonds have almost the appearance of metallic lead.

Owing to the high refractive index, most of the rays of light travelling inside a cut diamond will be totally reflected (p. 58); and owing to the high dispersion, the rays of white light are split up into red, green and blue rays. The fire and the play of colours are shown most prominently by stones which are perfectly colourless and free from flaws, that is, stones of the first water. The presence of even a slight coloration detracts from these effects; and for this reason the slightly yellowish Cape diamonds are of less value than the perfectly colourless stones from Brazil and India. An intense coloration, combined with perfect transparency, is very rare in diamond; the commonest colour is yellow, after which follow green, red and blue. In the collection of Mr. Tornow, of Frankfurt-on-Main, there are in addition to perfectly colourless faceted stones, others of a pale yellow, dark yellow, brown, rose-red, delicate violet, pale green, aquamarine-coloured, and black, all of faultless quality. The best example of a coloured diamond is the celebrated "Hope Blue" stone. Diamonds of a deep black colour and brillliant lustre are very rare; these are found in Borneo, and are used in the most expensive mourning jewellery.

Cloudy diamonds with a lead-grey colour and often traversed by fissures are known as *bort*; and the majority of stones which are found are of this poorer quality.

Diamond is perfectly transparent to the Röntgen rays, its transparency exceeding that of any other mineral. This affords a ready means of distinguishing a faceted

diamond from any other stone or glass imitation which it may resemble in appearance. Under the influence of the rays emitted by radium it becomes strongly phosphorescent, and this also gives a means of distinguishing it from other precious stones (p. 181).

In its *crystalline form* diamond presents several points of interest. In the first place, the crystals are developed on all sides, so that they must have grown while freely suspended in some medium; attached crystals have not been observed. The crystals belong to the cubic system and are often octahedral in habit (plate 41, figs. 1, 2 and 3). Octahedra of diamond differ, however, from those of other minerals in the fact that their edges are not sharp but rounded, as represented diagrammatically in text-fig. 165. This rounding of the edges may possibly be a peculiarity of growth of the crystals, or it may be due to twinning. Other crystals have the form of the rhombic-dodecahedron (plate 41, fig. 5), but with rounded faces and edges, and as this curvature of the faces increases there may be a gradual transition to the hexakis-octahedron (fig. 6, and text-fig. 166). Another form is the four-faced cube with curved faces, which is usually combined with the cube. In addition to these holohedral cubic forms, tetrahedra have been found, indicating that diamond belongs to the tetrahedral-hemihedral class of the cubic system.

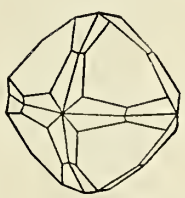

Fig. 165.
Octahedron with curved edges.

Fig. 166.
Hexakis-octahedron with rounded faces.

Crystals of Diamond.

The rounded octahedral form is well shown by the unusually large crystal represented in its natural form and size in fig. 167; this stone, known as the "Victoria" diamond, weighed in its rough state 457½ carats, but by cutting was reduced to 180 carats. The largest known diamonds (the "Excelsior", fig. 169, and the "Cullinan") are only portions of crystals and their octahedral form is not so obvious.

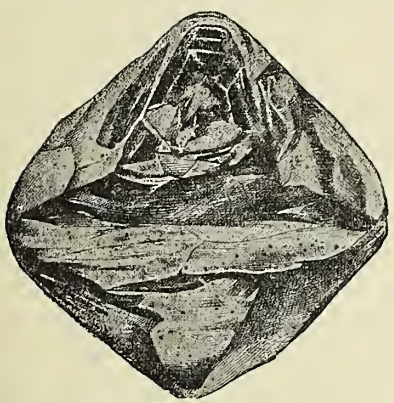

Fig. 167.
The "Victoria" diamond. An octahedral crystal with rounded faces and edges. (Natural form and size).

Twinned crystals have an octahedron face as twin-plane, as in magnetite, and are usually flattened parallel to the twin-plane; twinned rhombic-dodecahedra are often lenticular (fig. 168), and can only be used for cutting as rosettes.

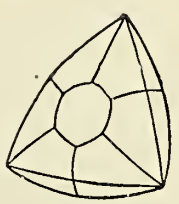

Fig. 168.
Twinned crystal of Diamond.

The faces of diamond crystals frequently show special markings: the octahedron faces being pitted with numbers of minute shallow depressions with a triangular outline, and the cube faces with depressions square in outline.

A special variety of diamond is that known as *carbonado* (also called "carbon" and "carbonate"), which has somewhat the appearance of coke. This is a black, finely granular and more or less porous aggregate of minute crystals of diamond. It is found in Brazil as pieces the size of a nut or at the most the size of a man's fist; the largest piece weighed 650 grams. It possesses the same hardness as crystals of diamond and at the same time is much tougher, and less frangible: the reason for this being that the mass as a whole is not cleavable, since it consists of small crystals aggregated irregularly. Owing to its extraordinary hardness, toughness and compactness, the unattractive-looking

carbonado finds an important application in rock-boring: being set in the crowns of rock-drills it is indeed a crown jewel of some practical use, and without its aid the modern method of tunnelling would scarcely be possible.

That diamond consists of a combustible material was suspected by Newton, by reason of its high refractive index. That is consists of carbon and burns in the air to carbon dioxide was as good as proved by Lavoisier, but an exact demonstration of this fact was first given by Tennant in 1797 and more recently by Krause. Diamond consists in fact of *pure carbon*, and small splinters of it can be made to burn even in a gas flame, and still more readily when heated in oxygen. Traces of foreign substances are often present, and these remain behind as ash when the diamond is burnt. When heated under certain conditions to a high temperature, diamond becomes converted into the soft, black modification of carbon known as graphite.

The high *specific gravity* of 3·52 is a remarkable feature of diamond; in the porous carbonado it may, however, be as low as 3·14. This being much higher than the specific gravity of graphite, we can conclude that in diamond the molecules are very closely packed together. Amongst other colourless precious stones, topaz has almost exactly the same specific gravity as diamond, but the two are readily distinguished by the much stronger fire of diamond; further, diamond is singly refracting, or optically isotropic, whilst topaz is doubly refracting and optically biaxial. The other colourless precious stones (zircon, phenacite, rock-crystal) also differ from diamond in being doubly refracting, and further in their higher (zircon) or lower (phenacite and rock-crystal) specific gravity. A highly refracting glass cut in the form of a brilliant may closely resemble a diamond in fire and lustre, but this can always be distinguished from diamond by its softness, low conductivity for heat, and opacity to the Röntgen rays.

Enclosures of foreign substances are occasionally seen in diamond; these are always quite small, but they are of importance, since they detract from the value of the stone and they throw much light on the origin of the diamond. The following minerals have been observed as enclosures in diamond: haematite or ilmenite, quartz, rutile, iron-pyrites, topaz, and gold. On the other hand, diamond itself sometimes occurs enclosed in other minerals, for instance garnet.

The *artificial production* of diamond has been often attempted, owing to the high intrinsic value of the stone. A few of these attempts have resulted in the formation of minute crystals, but not of sufficient size to be of use as gems; nevertheless these results are of considerable scientific interest, and they indicate to us how diamond may have been formed in nature. It has long been known that carbon is dissolved in molten iron, and that on cooling it separates again as graphite. If, however, the molten mass be very quickly cooled under an enormous pressure a small portion of the carbon crystallizes as diamond, as was proved by the researches of the late Professor H. Moissan. This mode of formation of diamond helps to explain the occurrence of diamond in meteoric iron, and in steel and hard cast-iron. Diamond can also be produced artificially without the help of great pressures as proved by the experiments of J. Friedländer and Hasslinger, who obtained minute crystals by adding carbon to molten olivine. This mode of formation explains the occurrence of Cape diamond in an olivine-rock. Graphite together with diamond have been formed by the decomposition of acetylene at a very high temperature (2000—3000° C.); and recently A. Ludwig has described a method by which carbon may be directly converted into diamond.

The *occurrence and origin* of diamond in nature still present many problems to be cleared up. At most localities it is clear that the diamond is not found in the rock in which it was formed, being often met with in the sands and gravels of rivers.

In South Africa, however, it is found in an olivine-bearing rock of igneous origin and it is not unlikely that the crystals have been formed in such a rock while in a molten state in the earth's interior, and subsequently brought near the surface by volcanic forces.

Of the *localities* at which diamond is found, the earliest known are several places in *India*. It is from here that the fabulous treasure of Indian princes was obtained; and from the time of the Romans until the middle of the eighteenth century but few diamonds had been found in any other country. The diamond-yielding districts lie on the eastern side of the Deccan plateau, extending for a considerable distance from south to north in the basins of the rivers Penner, Kistna and Mahanadi, and in the neighbourhood of Panna in Bundelkhand. Throughout this wide area the diamond occurs in a thin bed of earthy material rich in pebbles; this bed is of sedimentary origin, but the original rock from which the diamonds were derived is not known. In places where this diamantiferous layer has become exposed by denudation the material has been removed by running water, and the diamonds are found amongst the pebbles in the beds of the present streams and rivers. Indian diamonds are noted for their purity of water, brilliant fire and play of prismatic colours, and in many cases their size. The majority of the famous historical diamonds are of Indian origin, and this is especially true of the few red and blue stones which are known. Since the discovery of diamonds in Brazil the production from India has fallen considerably, and still more so when the market became flooded with Cape diamonds.

In *Brazil*, diamonds were first found in the year 1725. The most important districts are situated in the neighbourhood of the town of Diamantina in the state of Minas Geraes, and in the state of Bahia. The minerals found in association with diamond in Minas Geraes are quartz, rutile, anatase, tourmaline, haematite, monazite, etc.; all of these are found also in the quartz-veins (in which, however, the diamond itself has not yet been found) which traverse the ancient rocks of the district, as well as in the sedimentary rocks formed of the débris of the quartz-veins and enclosing rocks. The oldest of these sedimentary rocks is a micaceous sandstone which possesses the pecularity of being flexible in thin slabs: this is known as flexible sandstone or as itacolumite (from Mount Itacolumi, one of the localities where it occurs). This rock in turn has also been subjected to weathering processes, and its débris, with diamond and the associated minerals, caps many of the hill tops in the neighbourhood of Diamantina. Some of the débris has been transported by running water and deposited as pebbles in the valleys, forming alluvial deposits on the sides of the valleys or on the present flood plains. The more frequently and the farther these material have been transported the rounder are the pebbles. The loose material of these alluvial deposits has in many cases been later bound together by a ferruginous cement; and it is in such material that the diamond represented in plate 41, fig. 7, is embedded. A clayey deposit mixed with pebbles and containing diamonds is known to the Brazilians as "cascalho". The diamonds of the Brazilian deposits have thus frequently changed their position, just as, after being cut as gems, they pass from one possessor to another.

The mode of occurrence of diamond in the state of Bahia is much the same as in Minas Geraes. Here a special rich find was made in the year 1844 in the Serra da Cincorá; it is at this place that most of the carbonado variety is found, very little coming from Minas Geraes and South Africa, and none from India.

On the average, Brazilian diamonds are much smaller than those from India and from South Africa: the majority of them weigh $^1/_4$ carat or less. The largest that has been found is the "Star of the South", which weighed $254^1/_2$ carats, and when cut as a brilliant 125 carats. The most frequent forms are the cube, the rhombic-dodecahedron

and lenticular twin-crystals. In quality the stones approach those from India, and are better than the Cape diamonds.

From the time of the first discovery up to the year 1850 the production of diamonds in Brazil has been estimated at the value of £ 15,825,000, more than half of which was from Minas Geraes. At the present day the deposits are still not exhausted, and it is certain that other deposits remain to be discovered in this little-explored country.

In *South Africa* the first diamond was found in the year 1867. A shining stone picked up by some Boer children and used by them as a plaything was found to be a diamond; this crystal weighed $21^3/_{16}$ carats, and was shown at the Paris Exhibition of 1867. Other large stones were soon afterwards found, and then commenced the rush to the diamond diggings and a large population soon sprung up in a region which previously was only thinly inhabited. The first diggings were along the banks of the Vaal River in Griqualand West, Cape Colony; and in these "river diggings" diamonds were separated by the process of washing from the sand and pebbles. Very soon afterwards diamonds were also found on the arid plateau to the south of the Vaal River, at a spot where now stands the town of Kimberley, also in Griqualand West. Here, with an absence of water, the workings came to be known as "dry diggings"; they were the beginnings of the enormously rich and famous mines, the Kimberley mine, De Beer's mine, Du Toit's pan mine, and the Bultfontein mine, all in the immediate vicinity of Kimberley. The Jagersfontein mine and the Koffyfontein mine in Orange River Colony are also mines of the same character and discovered at about the same time.

The diamond-bearing rock of these mines is a kind of serpentine which has resulted by the weathering of an olivine-rock; it fills funnel-shaped depressions or pipes of unknown depth which penetrate the surrounding rocks. The latter consist of almost horizontal beds of shale, quartzite and sheets of diabase, and are sharply separated from the material in the pipes. The pipes are explosion-funnels formed by volcanic eruptions, and in their form are comparable with the crater-lakes (Maaren) of the Eifel. Their outline at the surface is approximately circular or elliptical; they measure from 200 to 300 metres across, and when first found they projected but slightly above the general surface of the ground. The rock is not slaggy and cellular like that of other volcanic necks, but is completely brecciated and fragmented, this structure being probably due to a series of steam explosions under a high pressure. With decreasing pressure and temperature the water condensed, forming a mud of the fragmented materials, which filled the funnel up to the top. The rock as we now find it is essentially a hydrated magnesium silicate, having much the composition of serpentine, and indicating that the original rock was largely composed of olivine, which is an anhydrous magnesium silicate. At greater depths in the pipes this material is dark blue or slate-grey in colour, and it is therefore known as the "blue ground": fragments of this "blue ground" with embedded diamonds are represented in plate 41, figs. 4 and 5. Nearer the surface, down to a depth of about 25 metres, the rock has been oxidized by atmospheric weathering and become yellow, being then known as "yellow ground" (fig. 6). Other minerals, besides diamond, found embedded in the "blue ground" are garnet (as transparent grains of a fine red colour, and known as "Cape ruby"), enstatite, chrome-diopside, ilmenite, etc.

Owing to the soft nature of the "blue ground" the winning of diamonds from it is a comparatively easy matter. Down to depths of 100—200 metres the material filling the pipes has been excavated in open workings; but at greater depths a regular system of underground mining has to be adopted, a vertical shaft being sunk and levels driven from this into the "blue ground". When raised from the mine, the material is spread out on "floors", and there watered and occasionally turned over; after being so

left to the action of the weather for about a year it becomes crumbly, so that the diamonds and other heavy minerals can be readily separated by a simple process of washing. From the mixed lot of heavier stones so obtained, the diamond was formerly picked out by hand, but recently a mechanical sorting table has been devised. This depends on the fact that diamond adheres to a greasy surface more readily than do the other minerals.

Amongst the diamonds separated from the "blue ground" there are, besides perfect crystals, many splinters and fragments of crystals. This breaking up of the crystals is not a result of the operation of extraction, for the matrix has not been reduced by crushing; and moreover fragments which fit together are never found. It is without doubt a result of the volcanic eruptions by means of which the material was brought up from great depths in the earth's crust. As already mentioned, some of the crystals of diamond are in a state of strain, and burst of their own accord without any apparent cause; it is therefore likely that stones of this character, when suddenly brought up from great depths to regions of less pressure, would be fragmented. Stones of this kind are usually of a smoke-grey colour with a very bright lustre; they are known as "smoky stones", and are of no use for cutting. Such stones cannot always be recognized by the unaided eye, but when examined under the polariscope they are seen to be more or less strongly doubly refracting, like compressed or unannealed glass, while normal crystals of diamond are singly refracting

Although the diamond mines at Kimberley yield numerous stones, they are only very sparingly distributed through the "blue ground". A hundred wagon loads of "blue ground" from the De Beer's and Kimberley mines yield 70—80 carats of diamonds, while the same amount from the Premier mine yields only 30—40 carats. In other words, about six tons of the matrix from the richest mines must be washed in order to obtain one gram (5 carats) of diamond, and only a small proportion of this is suitable for cutting. Stones of comparatively large size are, however, often met with; stones up to 20 carats in weight, which are rare in Brazil, are here common.

The largest known diamond was found on January 25, 1905, in the Premier mine near Pretoria in the Transvaal, which is a mine of exactly the same type as the Kimberley mines: this stone, known as the "Cullinan" diamond weighed before cutting $3025\frac{3}{4}$ carats (or $1\frac{1}{3}$ lb. avoirdupois) and measured 4 by $2\frac{1}{2}$ by 2 inches. It was a portion, probably not more than half, of a distorted octahedron. The next largest diamond, the "Excelsior" (fig. 169), was found in 1893 in the Jagersfontein mine in Orange River Colony: this weighed $971\frac{3}{4}$ carats and was the size of a hen's egg. Other large South African diamonds are the "Victoria" of $457\frac{1}{2}$ carats (fig. 167), and the "De Beers" of $428\frac{1}{2}$ carats, the latter being a very regularly formed octahedron with rounded edges.

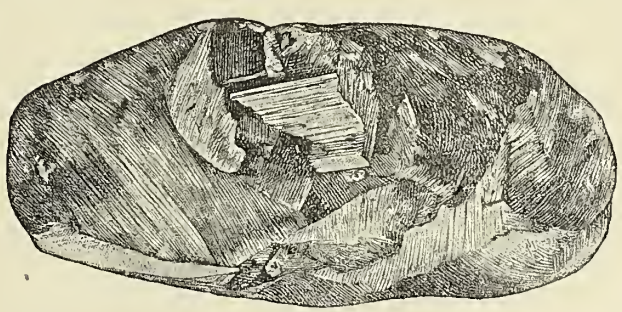

Fig. 169.
The "Excelsior" diamond. Actual size.

As a rule, the quality of South African diamonds is inferior to that of Indian and Brazilian, since they often show a faint yellowish tinge of colour. Although this yellowish colour is scarcely appreciable in itself, it is readily noticed when a Cape diamond is placed side by side with a Brazilian. The finest, and at the same time

the rarest, stones are of a so-called "blue-whites"; the slightly yellowish stones are called "Cape whites".

Since the whole of the Kimberley mines were taken over and worked by the De Beers Consolidated Mines, the output has been regulated with a view of keeping the price of diamonds high and steady. The annual output amounts to $2^1/_2$—3 million carats, valued at about four million pounds sterling. Owing to the great value of such small objects as diamonds, special precautions have to be taken to guard against thieving. The native workers in the mines live entirely, during their time of contract, in a carefully guarded enclosure called a compound, and before they are allowed to leave they are exhaustively searched and dosed with purgatives. In spite of all precautions, however, it is estimated that something like a quarter of a million pounds' worth of diamonds are stolen every year.

As to the origin of the diamond in these pipes, it is certain that the mineral was brought up from great depths together with the rock in which it is now found, and that it must have been already formed before the eruption of this material. It is probable that the diamond crystallized out from a molten magma at some considerable depth, and that the magma had the composition of an olivine-rock and contained some carbon in solution. This view is supported by the experiments of Friedländer, which prove that carbon is capable of crystallizing as diamond from fused olivine; and it receives still further support in the experimental fact that diamond can be dissolved in molten "blue ground". It is thus probable that, in South Africa at least, diamond has originated as a separation from an igneous magma, and it is also probable that this has been its mode of origin in other countries, although it has not been elsewhere observed in its mother-rock. Bearing on the origin of the diamond, the recent discovery of crystals of diamond in blocks of a garnet-pyroxene rock (eclogite) in the "blue ground" is of some importance.

As compared with the three countries just mentioned, others in which diamond has been found are of little importance as regards production.

In *Australia*, diamonds have been found in some of the gold-fields and in deposits of stream-tin, particularly in New South Wales, but never as stones exceeding six carats in weight.

In *Borneo*, on the south and south-east sides of the island, not a few diamonds have been found. Most of them are, however, quite small, 95 per cent. weighing less than one carat. In the possession of the Prince of Landak and the Rajah of Mattan are stones weighing over 50 and 100 carats. Some of the stones are perfectly transparent and water-clear, but more frequently they are yellowish, or sometimes rose, red, bluish, smoky or black. Those of a red or blue colour are very rare and are therefore highly prized; black stones are still rarer, probably because they are in great demand by the natives, who wear them as amulets to guard against misfortune. Associates of the diamond in Borneo are gold, platinum, corundum, rutile, and other minerals.

In the *United States* of North America only a few scattered diamonds have been found; the largest, found in the surface soil in the village of Manchester, Virginia, weighed $23^3/_4$ carats.

In *British Guiana* the occurrences are of more importance, and in the valley of the Mazaruni river 3076 carats of diamonds were collected in the year 1901. The stones are usually small, none exceeding eight carats, but in quality they are comparable with the Brazilian.

In *Europe*, a few diamonds have been found in the Ural Mountains. On account of the similarity between the Brazilian and the Uralian gold and platinum occurrences

it was predicted by Alexander von Humboldt that diamond would be found in the Urals. During his visit to the Urals in company with Professor Gustav Rose a special search was made, and the first European diamond was discovered in 1829 in some gold-washings near Bissersk, the actual discovery being made, however, by Count Polier, who had accompanied the expedition part of the way. Since that time other diamonds have been found, the largest weighing $2^1/_2$ carats.

The occurrence of *diamonds in meteorites* (see p. 165), though only as grains of microscopic size, is of considerable interest. Those found in meteoric iron must have had the same mode of origin as the crystals artificially crystallized from molten iron by Moissan (p. 208). The presence of graphite with cubic forms has also been detected in some meteorites, and it is probable that these cubic crystals were originally diamond which had later become altered to graphite.

Applications. — That diamond is used mainly as a precious stone is well known; we have already described how it is cut, and how it may be distinguished from other colourless stones. The most important centre of the diamond-cutting industry is in Amsterdam, and here all the larger and more valuable stones are sent to be cut. Smaller but not unimportant works are situated in Paris, London, Berlin, Hanau and Idar. Besides being used as a gem-stone, diamond finds certain important technical applications by reason of its great hardness. As bort and carbonado it is set in the crowns of rock-drills, and it is also used for boring cannon. It serves as a pivot-support in the more delicate classes of instruments and machines. Pierced diamonds are employed by wire drawers. Crystals with naturally rounded edges are extensively used for cutting glass, this being the well-known glazier's diamond; while sharp splinters are used for writing on glass. Diamond powder is much used by lapidaries and gem-cutters, and it is in fact the only material with which diamond itself can be ground.

The *value* of faceted diamonds varies between wide limits according to the quality, colour, size and form of cutting. A one-carat brilliant of the first water was valued in the year 1878 (at the Paris exhibition) at 220 francs, one of ten carats at 3250 francs, and one of twenty carats at 11,400 francs. In 1903, for a one-carat brilliant of the best quality £25 was asked, and one of ten carats £600 to £700. The value of stones of the second water is about two thirds of that for stones of the first water. Rosettes fetch about four-fifths the price of brilliants. Specially large stones or those of a pronounced green, red or blue colour, being quite exceptional, commanded fancy prices, and no rule can be laid down.

Large and famous diamonds have in all times generally been used as crown jewels or in the possession of princes, but they have often changed hands. The "Regent", or "Pitt", now shown in the Louvre with the French crown jewels was found in 1701 in the Partial mines in India; it weighed in its rough state 410 carats and was cut to a brilliant of $136^{14}/_{16}$ carats; in 1791 it was valued at twelve million francs (£480,000). The celebrated "Koh-i-noor", now amongst the English crown jewels, formerly belonged to the Rajah of Lahore, from whom it was taken by the East India Company and in 1850 presented to Queen Victoria. In its Indian form of cutting it weighed $186^1/_{16}$ carats, and in 1852 it was re-cut as a brilliant weighing $106^1/_{16}$ carats; it has been valued at £100,000. The "Orloff" is the largest diamond in the Russian crown jewels; it weighs $194^3/_4$ carats, and has the form of a high and irregular rosette. The "Florentine", now in the state treasury at Vienna, weighs $133^1/_5$ carat; it is pale yellow, and is cut as an egg-shaped double rosette, or briolette. It is said to have once belonged to Charles the Bold, lost by him in the battle of Granson, and found again by a Swiss soldier. Similar adventures are related in connection with the "Sancy"

($53^{12}/_{16}$ carats), now the property of an Indian prince. All the celebrated gems so far mentioned are of Indian origin. Of Brazilian stones, the largest is the "Star of the South", which in the rough weighed $254^{1}/_{2}$ carats, and cut as a brilliant 125 carats; this also is in the possession of an Indian prince. The "Star of South Africa", a stone of the first water and weighing $83^{1}/_{2}$ carats, was found in 1869 in the Vaal River diggings; it was cut as an oval, three-sided brilliant of $46^{1}/_{2}$ carats, and was sold to the Countess of Dudley for nearly £25,000. Since that time still larger diamonds have been found in South Africa, the largest of which, the "Cullinan" and the "Excelsior", have already been referred to above. The "Cullinan", presented to King Edward VII by the Transvaal government, has recently (1908) been cut in Amsterdam into a large number of brilliants, the largest weighing $516^{1}/_{2}$ carats and another $309^{3}/_{16}$ carats.

Amongst coloured diamonds of large size, the following are especially noteworthy. The "Hope Blue", named after one of its former possessors, combines the blue colour of the sapphire with the fire and play of prismatic colours of the diamond; it is a brilliant of $44^{1}/_{4}$ carats and came from India. A pale blue diamond weighing 40 carats is preserved in the Bavarian state treasury. The best known green diamond, the "Dresden Green" kept in the "Green Vaults" of Dresden, is an almond-shaped brilliant of 40 carats.

Graphite.

Graphite, like diamond, consists simply of the chemical element carbon, and yet there is the most striking difference between these two minerals. Diamond is the hardest, and graphite the softest of minerals; diamond is colourless and perfectly transparent, while graphite is black and opaque; diamond is a non-conductor, and graphite a good conductor of electricity; diamond occurs as beautifully developed octahedral crystals, while graphite usually forms only lamellar and scaly masses. Similar cases of dimorphism, where two substances are identical in chemical composition but different in all their physical characters, are by no means uncommon, but it is not often that the two substances present such striking differences as do diamond and graphite. The present example may be compared with the two carbon compounds cellulose (woody fibre) and starch, which also are identical in their percentage chemical composition. Starch, which is largely present in grain and potatoes, is an important food-stuff and can be readily converted into other substances, such as sugar and alcohol; cellulose, on the other hand, is very stable and cannot be converted into sugar or alcohol, nor has it any nourishing properties. Attempts made by chemists to convert coal into diamond have at last been successful on a small scale, but not so with the conversion of cellulose into starch. We learn from chemists that, although cellulose and starch are found by quantitative analysis to be identical in composition, yet the chemical elements are combined in different ways in the two substances and that their chemical molecules are therefore different. In the same way, we must assume that the molecules of diamond and graphite are not identical; the molecules of one may contain a larger number of atoms than the molecules of the other, or the atoms may be linked together in a different manner in the two kinds of molecules. The two minerals are, in fact, not only different in their physical characters, but also in their chemical behaviour. Graphite, when heated with an oxidizing mixture of potassium chlorate and nitric acid, gives rise to a yellow powder of complex composition known as graphitic acid; but this substance cannot be prepared from diamond.

Graphite occurs in nature as lamellar, scaly or fibrous aggregates, or in almost compact masses. It is iron-black to dark steel-grey with a metallic lustre, and possesses a perfect cleavage in one direction. Platy and fibrous masses of this kind are represented in figs. 8 and 9 respectively of plate 41. Crystals are of rare occurrence and belong probably to the hexagonal system; they have the form of six-sided plates but are never very distinctly developed.

Owing to its very low degree of hardness (H. = 1—2) graphite is greasy to the touch and readily soils the fingers. Its specific gravity of 2·2 is much lower than that of diamond. Thin flakes of the pure mineral can be burnt in the flame of the Bunsen-burner. Usually, graphite contains an intermixture of incombustible materials, which when the material is burnt remain behind as ash: this may be present to the extent of 13 per cent. or even more, and the material may still be useful for certain technical purposes.

A liquid capable of dissolving graphite and other forms of carbon is molten iron. When the carbon in grey cast-iron exceeds a certain amount, it seperates again on cooling, usually in the form as graphite, and sometimes as quite good though small crystals.

In nature, graphite is found as a constituent of crystalline rocks; and in certain cases it may constitute the bulk of the rock, as in graphite-schist. When occurring under these conditions, graphite has usually been formed from coal or other carbonaceous material by the contact-action of intruded igneous masses. Another mode of occurrence is in veins; and here the mineral has probably been deposited by gases or vapours ascending through the earth's crust. In support of such a view we know that certain gases, such as acetylene and vapourized silicon carbide, deposit graphite when heated.

Some of the more important localities for graphite are the following. Borrowdale in Cumberland, Pfaffenreuth near Passau in Bavaria, Miask in the Ilmen Mountains in the Urals, on the rivers Kureika and Nishnaya in government Yeniseisk, and particularly in the Batugolskoi-Golez in government Irkutsk in Siberia. At the last named locality is the celebrated Mariinskoi graphite mine worked by Alibert and Faber; it is situated in the Tunkinsk mountains between the rivers Besimiannaia and Batugol and about 400 kilometres to the west of Irkutsk. In the United States, graphite is extensively mined at Ticonderoga on Lake George in the state of New York. The richest deposits are those in Ceylon, which yield not only the largest amount but also the best quality of graphite: the two specimens represented on plate 41 are both from here.

The best qualities of graphite are used in the manufacture of pencils, and the inferior qualities for crucibles, stove polish, oven plates, black pottery, dry lubricants, foundry facings, etc. Artificial graphite is now prepared on a large scale by means of electrical power at the Niagara Falls.

Corundum.

The species corundum includes several colour-varieties which are of considerable importance as gem-stones, and which were distinguished by special names long before it was known that they were identical in their chemical composition and other essential characters. The red variety is known as ruby, the blue as sapphire, the yellow as "oriental topaz" or yellow sapphire, and the violet as "oriental amethyst" or violet ruby, whilst cloudy specimens with no pronounced colour are distinguised as common corundum. Each of these varieties may be further described as "precious", when it is desirable to

distinguish between a transparent stone and one of the same colour but cloudy and of little value. Stones of deeper and richer colour are sometimes described as "masculine," and those of a paler colour as "feminine". Finally the prefix "oriental" is employed to distinguish between corundum gems and other minerals possessing the same colour. Thus, "oriental ruby" is the true ruby, and the name ruby alone is on this account sometimes incorrectly applied to red spinel. "Oriental amethyst" is violet corundum, the true amethyst being a violet coloured variety of quartz. Before describing each of these varieties of corundum in detail, we shall outline the characters which they possess in common, that is, the general characters of the species corundum.

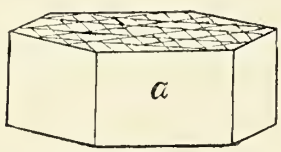

Fig. 170.

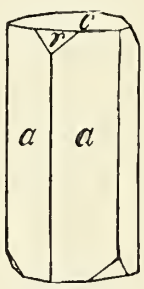

Fig. 171.

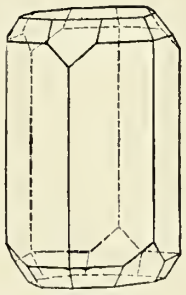

Fig. 172.

Crystals of Corundum (Ruby).

The mineral corundum consists of aluminium and oxygen in combination as alumina, Al_2O_3. It is never absolutely chemically pure, but always contains some iron oxide (1—2 per cent.) and frequently traces of chromium: these impurities give the colour to the material, since pure alumina is a colourless compound.

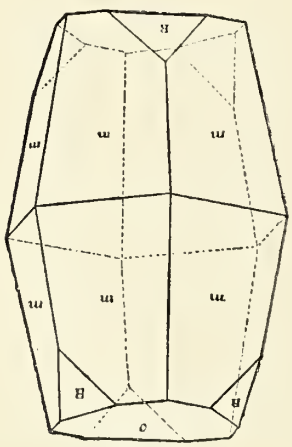

Fig. 173.
Crystal of Corundum (Sapphire).

Crystals of corundum belong to the rhombohedral division of the hexagonal system. The simplest form is a combination of a hexagonal prism with the basal pinacoid (text-fig. 170, and plate 42, figs. 2, 16 and 17). When faces of a rhombohedron are also present they truncate alternate corners between the prism and the base (*r* in text-fig. 171; plate 42, fig. 10), proving the prism to be that of the second order. Sometimes a hexagonal pyramid of the second order may also be present as faces truncating the edges between the prism and the base (text-fig. 172). The Naumannian symbols of these forms are respectively $\infty P2$, $0R$, R, $\frac{4}{3}P2$. When the prism is long the crystal has a prismatic habit (fig. 10), and when short a tabular habit (fig. 12). In other crystals the habit may be pyramidal, either with the pyramid alone (fig. 11), or in combination with the base (figs. 1, 15 and 18) or a rhombohedron (fig. 3, and text-fig. 173). The steep pyramid in figs. 11 and 6 has the symbol $\frac{8}{3}P2$. Whatever the habit of the crystals, they are always thick and lumpy, delicate forms of growth never occurring in corundum. In crystalline form, as well as in the type of chemical formula, there is a close similarity between corundum and haematite, the two minerals being isomorphous.

Well-developed twin-crystals of corundum are of rare occurrence; a specimen consisting of two individuals twinned on a face of the primary rhombohedron *R* is represented in plate 42, fig. 7. On the other hand, thin twin-lamellae parallel to the faces of the rhombohedron *R* are frequent both in crystals and compact masses, giving

rise to planes of easy separation or false cleavage in these directions. Owing to this, corundum may sometimes be broken up into rhombohedral blocks (fig. 21) closely resembling cubes in form, the rhombohedral angle being 86° 4′. The twin-lamellae also give rise to striations on the faces of the crystals; on the basal plane these run in three directions (text-fig. 170), if the twinning is repeated on all three faces of the rhombohedron; and on a rhombohedral face or plane of separation in two directions. When, in cloudy corundum, the twin-lamellae are very fine the stone reflects from the basal plane a six-rayed star of light, which is shown to the best advantage if the stone be cut with a rounded surface and polished (*en cabochon*); this appearance is well shown in the variety known as star-sapphire.

The refractive power of corundum is high, but the double refraction feeble; the index for the ordinary ray being 1·769 and for the extraordinary 1·760. The dispersion also is not strong, so that in all these optical characters corundum does not approach the diamond. It, however, exceeds topaz, beryl and quartz in its refractive power, and therefore also in its lustre. When examined with the dichroscope, coloured stones are seen to be distinctly dichroic. The mineral is moderately transparent to the Röntgen rays.

Since the material is composed of the light elements aluminium and oxygen we should not expect it to be heavy; as a matter of fact, however, the specific gravity is unusually high, varying between 4·0 and 4·1. Corundum is thus one of the heaviest of precious stones, and in this respect is exceeded only by zircon and certain varieties of garnet.

Also in its hardness, corundum occupies a prominent position. Although the difference in hardness between diamond and corundum is very considerable, there is no other mineral with an intermediate hardness. The artificial product known as carborundum (carbon silicide) occupies such a position; and being harder than corundum, it is now largely used in place of this for grinding precious stones.

Ruby is a red coloured variety of corundum. The colour varies between delicate rose, carmine-red, brownish-red and bluish-red, and the shade most highly prized is the so-called pigeon's-blood red; some of these colours are represented in plate 42, figs. 10—16. When ruby is raised to a red-heat, its dark red colour changes first to a dirty red, then to a greenish-blue, and on cooling again the stone regains its original red colour and transparency. These changes in the colour may be readily observed by heating a ruby in a crucible of fused silica, especially if during the cooling a sheet of white paper be held beneath. From this behaviour we can conclude that the colouring matter is inorganic, since at a red-heat any organic colouring matter would be destroyed. No doubt the colour is due to the small amount of chromium oxide always present in ruby.

The dichroism of ruby can sometimes be observed by the unaided eye: a transparent crystal will be seen to be darker when we look through the basal plane and lighter through the prism planes. This is a point to be taken into account by the gem-cutter; if he wishes to get the deepest colour possible he must so cut the stone that the large table facet will be parallel to the base, while if he wishes to somewhat reduce the colour of a very dark stone the table facet should be perpendicular to the base. When examined with the dichroscope, the crystal will show the maximum difference in colour of the two images when it is viewed through the prism planes. The image corresponding to the extraordinary ray (*e*) will be pale red with a yellowish tinge, and the image corresponding to the ordinary ray (*o*) dark red with a violet tinge. The crystal represented in fig. 11 showed the two colours yellowish-pink (*e*) and dark violet (*o*) respectively, and the faceted stone in fig. 13 yellowish-red (*e*) and violet-red (*o*). On looking through the large table facet of a cut stone the two images seen in the dichroscope will, as a rule, be of the same colour, since, if the stone is properly cut, we are then looking along the principal

axis and in this direction there is no dichroism. If such a stone be examined in the polariscope with the table facet resting on the stage, we will see a series of concentric coloured rings intersected by a black cross (i. e. a uniaxial interference-figure, plate 4, fig. 1): by placing a drop of oil on the stone the light will be better able to pass through, and the figure will be more distinct.

Crystals of ruby are usually bounded by faces of the hexagonal prism of the second order, the basal pinacoid, and a rhombohedron (fig. 10); a hexagonal pyramid of the second order may also be present, but only in rare cases does this predominate ($\frac{8}{3}P2$ in fig. 11).

Most of the best rubies used in jewellery come from Mogok in Upper Burma, where they occur with precious spinel in white marble; the weathering of this rock results in the formation of a clayey material, in which the rubies are also found, as well as in the sands of the neighbouring streams. Another very similar, but less important, occurrence in Upper Burma is in the Sagyin Hills near Mandalay. The stones are usually only quite small, seldom exceeding one carat in weight; clear stones exceeding ten carats are very rare and command a high price. The largest stones which have been found weigh over a thousand carats, but they are cloudy.

Other localities for ruby are situated in the provinces of Chantabun and Krat in the adjacent county of Siam. Most of the Siamese rubies (fig. 16) are of a brownish-red colour and are consequently much less valuable than the Burmese. Ruby mines have also been worked for a long period in Badakshan on the upper Oxus; the products of these mines passing mainly through Persia. In Ceylon (fig. 12) ruby is much less common than sapphire. Amongst American localities may be mentioned Newton in New Jersey (fig. 10), Lownes County in Georgia (fig. 15) and Macon County in North Carolina (fig. 17).

Ruby is generally cut in a flat brillant form or in the step-cut, and is set *à jour*. Its value depends on the clearness, shade of colour, and size of the stone. A faultless ruby of the best colour and weighing 3 to 5 carats fetches ten times the price of a diamond of the same weight; and for still larger stones no definite price can be stated. For a cut stone of $32^{5}/_{16}$ carats £10,000 has been paid, and for one of $38^{9}/_{16}$ carats twice this amount. Since the price varies widely with the clearness, colour and size of individual stones, it is difficult to state this exactly. On the average, a one-carat Burmese stone fetches from £2 10s. to £7 10s., while the dark coloured Siamese stones are worth about half of this amount. Paler stones are much more common and consequently cheaper. An idea of the size of a one-carat cut stone may be obtained from fig. 13 (weight, 0·2 gram = 1 carat): that represented in fig. 14 weighs 0·355 gram. Recently, cloudy ruby, which occurs as much larger crystals, has been cut and worn as necklaces.

Precious stones which may be mistaken for ruby are garnet (almandine and "Cape ruby"), spinel ("ruby-spinel" and "balas-ruby"), tourmaline (rubellite), and red topaz. Garnet and spinel being cubic minerals are singly refracting and are not dichroic, and the others differ from ruby in their specific gravity and refractive indices.

Owing to the rarity and high value of ruby, many attempts have naturally been made to prepare it in the laboratory, and recently with highly successful results. The methods employed will be mentioned further on at the end of our remarks on corundum. The stones of artificial origin can be distinguished from those of natural origin by the fact that under the microscope they show the presence of minute rounded cavities, or bubbles, and curved streaks; in the natural stones any minute cavities which may be present are angular in outline and the streaks are straight. Apart from these minute differences, however, there are no differences between the two, and many of

the artificial stones are of even a better carmine-red or "pigeon's-blood" red than the natural stones. These artificial stones are produced in large quantities and quite cheaply; but, since they can always be distinguished as artificial products, the high price of the natural stones is not thereby lowered.

Sapphire is a blue colour-variety of corundum. Here the crystals are more frequently pyramidal in habit; a steep hexagonal pyramid is shown in plate 42, fig. 6, in combination with the base in figs. 15 and 18, and with the base and rhombohedron in fig. 3. Fig. 2 shows the prism and the base, and fig. 7 a twin-crystal.

The colour of sapphire ranges from pale blue or almost colourless to a deep inky blue, the colour most sought being an intense cornflower-blue. The same stone may be differently coloured in different parts, there being lighter milky patches in dark stones and darker patches in light stones, while less frequently blue bands alternate with those of another colour: such a banded stone is represented in plate 42, fig. 4, where the large face to the front is the basal plane. A yellow colour is often associated with the blue, as in figs. 6 and 7, and in that case the value of the stone is very low. Some bluish-green stones show patches of a more decided blue or green colour (fig. 8); these are strongly dichroic, showing in the dichroscope indigo-blue and green images. Stones of a pure blue colour are less distinctly dichroic; the crystal in fig. 6 gives for the ordinary ray a pure blue and for the extraordinary ray pale green; while other crystals show dark blue and pale blue respectively. Owing to this dichroism, stones show the purest and deepest blue colour when they are cut with the table facet parallel to the basal plane. The colour of a sapphire is not seen to advantage by lamplight.

The degree of transparency varies between wide limits: some crystals are perfectly transparent, and these are distinguished as precious sapphire, while others are only translucent or quite opaque (figs. 1—9).

Properly, the name sapphire should be limited to corundum of a blue colour, but it is also usual to speak of white sapphire, yellow sapphire, etc.

Yellow sapphire ("oriental topaz" or topaz-sapphire) is applied to those specimens of corundum in which some shade of yellow is pronounced. When specially clear these frequently exhibit small cloudy and milky patches, a peculiarity which enables "oriental topaz" to be at once distinguished from other yellow gem-stones. The dichroism is very feeble; but the brilliancy and fire is specially strong, and in lamplight there is no diminution in the beauty of the stone.

Amethyst-sapphire (or "oriental amethyst") is violet corundum with a distinct tinge of red. This is quite a rare stone, and can be readily distinguished from the true amethyst by its much higher specific gravity and by its strong pleochroism. With a deeply coloured violet stone the dichroscope shows for the ordinary ray a bluish-violet and for the extraordinary ray a yellowish-red image. In lamplight the colour appears redder, whilst the true amethyst becomes a dull grey.

Other gem-varieties of corundum may present colours resembling the aquamarine, chrysolite, emerald or hyacinth, and these are known by the corresponding names with the prefix oriental. These are, however, of rare occurrence, and their dichroism is usually only feeble.

Star-sapphire, or asteria, on the contrary, is commoner and of more importance. This is usually of an inconspicuous greyish-blue colour, though sometimes blue, violet or red (than properly a star-ruby), and is often quite cloudy. It characteristic feature is the six-rayed star of light which is reflected from the basal plane, due, as already explained, to the presence of numerous thin twin-lamellae in the stone. In order to show this star to the best advantage the stone should be cut and polished with a highly

convex surface (*en cabochon*) with the flat base of the dome parallel to the basal plane. If the stone be cut in a direction at right angles to this it will show only one band of reflected light on the surface, and being then like a cat's-eye, it may be called a sapphire cat's-eye. At the present time good star-sapphires are held in high esteem, and the sharper the star the greater is their value.

Sapphire occurs in nature as a constituent of rocks of igneous origin. Several crystals embedded in the felspar of a granitic rock from the Urals are represented in plate 42, fig. 5. Small grains of sapphire are also sometimes found scattered through basalt. Usually, however, sapphire is found in deposits of clay and gravel, which have resulted from the breaking down of the mother-rock.

The most important localities are in Siam, and then follow Burma, India, Ceylon, Australia and the United States of North America; at other localities only cloudy stones of little value as gems are found. Sapphires of the best colour are found at Pailin and Battambang in Siam: those from Ceylon are usually pale and patchy (figs. 6 and 7); those from Australia (Emmaville and Tingha in New England) and from the United States (Eldorado Bar in Montana) are often dark greenish-blue. Recently, stones of a deep and pure blue colour have been found in the upper course of the Judith river and at Yogo Gulch in Fergus county in Montana. Sapphire sometimes of a good colour, but usually cloudy or only slightly transparent, is found near Miask in the Ilmen mountains in the Urals. Grains of sapphire are found in the Rhenish basalt at Unkel, Niedermendig and other places; cloudy prismatic crystals in granite at Wolfshau in Silesia; and with cloudy ruby in the dolomite of Campo longo on St. Gotthard.

Sapphire has been known since ancient times, and on rare occasions it is been engraved as a gem, though on account of its great hardness it is not well adapted for this purpose. At the present day it is much worn in jewellery, and its value depends mainly on the depth and purity of its colour. The most highly prized stones are of an intense cornflower-blue with uniformity of colouring and a velvety appearance combined with perfect transparency.

A ten-carat stone of the best quality would be worth £50 to £75, while paler stones with an irregular distribution of colour are worth much less (12—15 shillings per carat). Stones which are banded with blue and yellow may sometimes be so cut that the upper portion of the gem is in a blue layer, while the lower portion, which is hidden as far as possible in the setting, is yellow: such a stone when viewed from the front may show a good blue colour, but when viewed from the side it will appear distinctly yellow. The dark greenish-blue Australian sapphires are now largely in use, and cost from eight to ten shillings per carat. Stones of other colours are as a rule, cheaper: the yellowish stone weighing 1·235 gram (about 6 carats) represented in fig. 19 was bought for thirty shillings. Violet sapphire costs about 15s. per carat, and star-sapphire 6s. or more depending on the quality.

From other precious stones of similar colour sapphire and other varieties of corundum can always be readily distinguished by the specific gravity. The cut stone in fig. 8, which might be confused with tourmaline, was found to have a specific gravity of 4·1, proving it to be corundum.

Common corundum is cloudy and not attractive in colour; it may be grey, yellowish, bluish (plate 42, fig. 21), reddish-brown (fig. 17) to dark brown (fig. 20) or almost black. The crystals may be combinations of the prism and base (fig. 17) or a pyramid and the base (fig. 20), with or without a rhombohedron. It occurs embedded in granite, gneiss, serpentine, crystalline dolomite or other rocks at the localities mentioned above for ruby and sapphire. Large deposits of common corundum occur in

the United States, a country which has also yielded some very large crystals, not only of corundum, but of many other minerals; the largest on record is a crystal weighing 312 pounds from the Culsagee mine in North Carolina. Massive corundum is sometimes known as admantine-spar, in reference to the hardness.

A fine grained mixture of sapphire with various iron ores constitutes the well-known *emery*. This is found especially in Asia Minor and the Island of Naxos, where it is interbedded in granular limestone or is met with in secondary deposits.

A mineral which frequently occurs in association with emery or common corundum is *diaspore*. This is usually found as greyish or yellowish foliated aggregates with a perfect cleavage and pearly lustre in one direction. In addition to alumina it contains some chemically combined water, the formula being $Al_2O_3 . H_2O$. It is a product of alteration of corundum and is found at the localities mentioned above for emery, and at Kossoibrod in the Urals and Chester in Massachusetts.

Artificial production of Corundum. — Crystallized corundum possessing all the characters of the natural mineral but of a dull grey or reddish colour is at the present day formed in large quantities as a by-product in the Goldschmidt process of preparing metallic chromium (p. 157) and in the electrolytic preparation of aluminium. Beautiful crystals of ruby were prepared in 1877 by Frémy and Feil; these are transparent and of a fine colour, but being in the form of thin hexagonal plates they are of little use for cutting as gems. One of the methods employed was to fuse at a high temperature (1500° C.) a mixture of amorphous alumina, potassium carbonate, calcium fluoride and potassium bichromate in a porous crucible. It is probable that under these conditions a series of reactions takes place: aluminium fluoride would first be formed, and this would be decomposed by the air and water vapour penetrating through the porous walls of the crucible from the source of heat. A still more successful process, by which fine rubies of almost any size and of good gem-quality are produced with ease, was devised in 1904 by Professor A. Verneuil of Paris. The material he uses is pure ammonium-alum, which, in a powdered form, is fed through the oxygen tube of an inverted oxy-hydrogen blowpipe. In the intensely hot flame the water, ammonium and sulphuric acid are volatalized and the alumina falls as a molten drop on a pedestal beneath and there crystallizes as corundum. As the operation is continued the corundum grows upwards as a pear-shaped drop or "boule". The material so obtained is colourless if the alum is quite pure and no colouring materials have been added: a ruby-red colour results by the addition of some chromium-alum to the ammonium-alum. Although these drops have a smooth rounded exterior with no external crystal-faces, they each consist of an individual crystal with an internal crystalline structure and identical in all their characters with naturally-occurring corundum.

Applications of Corundum. — Besides its use as a gem-stone, corundum has certain technical uses. Emery and massive corundum are powdered and sifted into grades of various fineness, the finest by washing in water, and used as an abrasive, either in the form of powder, as emery cloth, or as corundum wheels. In its use by lapidaries for grinding precious stones it has now largely been replaced by the harder carborundum. Corundum of the poorer gem-qualities are used for jewelling watches and other fine instruments, that is, as a hard bearing for steel pivots. The artificial corundum (known as corubin) produced in the Goldschmidt process exceeds emery in its hardness and abrasive power, and it is also used for the construction of refractory crucibles and moulds.

Appendix to Corundum.

Metallic aluminium was first prepared by Wöhler in 1827 by the reduction of aluminium chloride with potassium, and since then it had long been regarded as a metal of the future. At the present day it is obtained in large quantities from alumina directly. Corundum is, however, not formed in sufficiently large amount to be made use of, and the alumina employed is prepared from bauxite.

Bauxite is an earthy or clayey material of unattractive appearance, which when pure consists of alumina and water in approximately the proportions given by the formula $Al_2O_3.2H_2O$; it is, however, probably not a definite mineral species, but a mixture. It occurs as bedded deposits, and has been formed by a special kind of weathering process from basaltic and other rocks: and on this account it is frequently much intermixed with silica and iron oxide. With the percentage of iron the colour varies from white to yellow and brown. Extensive beds of this material are worked at Baux near Arles and other places in the south of France, and in County Antrim, and to a smaller extent at the foot of the Vogelsberg in Germany. The richest deposits are those of Georgia and Alabama in the United States, where in the year 1899 the output of bauxite amounted to upwards of 30,000 tons. Laterite, which is of wide distribution in tropical countries as a weathering product of granite, diorite, diabase and other rocks, also contains variable amounts of the bauxite substance.

The French bauxite, such as is used at Neuhausen on the Rhine for the manufacture of aluminium, contains alumina 60%, iron oxide 20%, silica 3—4%, and water 16—17%. From this mixture the iron oxide and silica are removed by chemical means, leaving a purified product containing on the average 99% of Al_2O_3. Metallic aluminium is extracted from this by electrolysis, the electrical energy being generated by water power, at Neuhausen on the Rhine, at Foyers in Inverness-shire, and at the Niagara Falls.

The electrolytic apparatus consists of an iron box thickly lined with blocks of carbon or better with fire-brick. A plate of copper or iron inside the box at the bottom, and connected to the exterior by a thick rod, forms the cathode, whilst the anode consists of a thick bundle of carbon rods. In order to start the process a mixture of alumina and cryolite is placed in the box and fused by the electric current of about 25,000 ampères per square metre of the cathode. Fusion takes place rapidly and metallic aluminium commences to separate on the cathode at the bottom of the vessel, which itself then forms the cathode. This is drawn off from time to time, but incompletely, sufficient molten aluminium being left behind in the box to continue to act as the cathode. The walls of the box are carefully cooled, otherwise the lining would be dissolved by the cryolite. More alumina is added from time to time, and the process proceeds continuously. The oxygen liberated at the anode combines with the carbon forming carbon dioxide, so that the anode has occasionally to be renewed. The temperature of the fused mass has to be carefully regulated, and the strength of the electric current must be kept as low as possible so long as the material remains fluid. During the continuation of the process the cryolite is decomposed to a slight extent and requires replenishing from time to time. The whole of the aluminium of commerce is now manufactured by this process.

Aluminium is remarkable amongst metals by reason of its very low specific gravity of 2·7. It can be cast in moulds, and being very ductile and not hard it is readily worked. If only it were resistant to saline solutions its applications would be still more extensive. It is largely used for the construction of vessels and pieces of apparatus in which a light weight is essential or desirable, for example, soldiers' flasks, boats of various

kinds, parts of telescopes and photographic apparatus. It is also drawn into wire and rolled into sheets. Aluminium foil is used for "silvering" picture frames.

Since in the preparation of aluminium a very high temperature is necessary for the separation of the metal from the oxygen, a very high temperature (up to 3000° C.) is generated when the metal again combines with oxygen. On this depends the Goldschmidt process for the preparation of metallic chromium (p. 157) and other difficultly fusible metals. By the ignition of "thermite" (a mixture of powdered aluminium and magnetic oxide of iron) iron tyres, rails, etc., can be welded and hard steel softened; the method having the great advantage that the intense heat can be applied quite locally without affecting other portions of the structure. It has been used, for instance, by burglars for attacking iron safes.

Alloys of aluminium and copper have been already mentioned above under the latter metal. Recently an alloy of aluminium and metallic magnesium, known as "magnalium", has been used in the form of thin plates, it having certain advantages over pure aluminium. An alloy of aluminium and iron, ferroaluminium, is employed in the metallurgy of iron, especially in the re-melting of old iron, it producing a sound and uniform casting.

The amount of metallic aluminium produced in the years 1897 and 1907 is given below in metric tons (of 1000 kilograms):

	1897.	1907.
North America	1815	16329
Switzerland, Germany and Austria	800	8000
France	470	4500
Great Britain	310	3700
Total	3395	32529

While fifty years ago aluminium cost at the rate of £170 per kilogram, the present price is about two shillings, or about a shilling per pound.

Spinel.

Spinel contains the same constituents, aluminium and oxygen, as corundum with the addition of magnesia. Although the composition is so simple, the exact constitution of the mineral is still debatable. It may be regarded as a combination of two oxides, that is, a double oxide analogous to a double salt, when the formula would be written $MgO . Al_2O_3$. On the other hand, it is also often considered to be a simple salt in which alumina plays the part of an acid, and the formula written $MgAl_2O_4$, representing an aluminate of magnesium. Here we shall adopt the first of these alternative views.

Spinel may be taken as the type of a large group of minerals, the spinel group, all of which possess the same crystalline form and are analogous in chemical composition, being therefore isomorphous. Certain members of the group approximate to the ideal compositions stated below, while others consist of isomorphous mixtures of these and occupy intermediate positions; the more important members are:

Precious spinel, $MgO . Al_2O_3$.
Hercynite, $FeO . Al_2O_3$.
Pleonaste, $(Mg, Fe)O . (Al, Fe)_2O_3$.
Magnetite, $FeO . Fe_2O_3$.
Gahnite, $ZnO . Al_2O_3$.
Franklinite, $(Zn, Fe, Mn)O . (Fe, Mn)_2O_3$.
Chromite, $(Fe, Mg)O . (Cr, Al, Fe)_2O_3$.

Of these, magnetite, gahnite, franklinite and chromite have already been described; and of the others, precious spinel is the most important on account of its use as a precious stone.

Precious spinel is often very similar to ruby in colour, and when clear and transparent it is known as *balas-ruby* (plate 43, fig. 1) and *ruby-spinel* (fig. 2); the former of these names being applied to stones of a deeper red colour, and the latter to paler stones; but in the trade both are often loosely spoken of as ruby. When the colour has a brownish or yellowish tinge the name *rubicelle* is used; and a reddish-violet spinel is called *almandine-spinel*, or incorrectly almandine, for almandine is really a variety of garnet. These red colours may be of various shades, from pale red to deep ruby-red, delicate violet to dark violet, or violet-red and brownish-yellow. Blue, bluish-green and green colours may also occur, but these are much less common.

From ruby, red spinel differs not only in its chemical composition (which is not, however, readily determinable), but also in its crystalline form and physical characters. It crystallizes in the cubic system, and most crystals have the form of the simple octahedron (plate 43, figs. 1 and 2), the edges of which are sometimes truncated by narrow faces of the rhombic-dodecahedron. Twinned crystals with a face of the octahedron as twin-plane (text-fig. 142, p. 155) are of frequent occurrence; and they are so typical of spinel that twins of this kind are known as spinel-twins, even when they occur in other minerals; for instance, a spinel-twin of magnetite is shown on plate 29, fig. 9. Crystals of spinel are, as a rule, quite small; and the twinned crystals are often flattened parallel to the twin-plane.

When crystal-faces are present there is no difficulty in distinguishing between ruby and spinel by mere inspection; in the absence of these, as in a faceted gem, the two minerals can be readily distinguished by their optical characters. Spinel, being cubic, is optically isotropic, and when examined in the polariscope, in either parallel or convergent light, it remains dark. The refractive index, 1·72, of spinel, is rather lower than that of ruby, though still high enough for the stone to be of considerable brilliancy: while owing to its high degree of hardness (H. = 8) it takes a good polish. To the Röntgen rays spinel is much less transparent than ruby. The red colour of spinel is probably due to the presence of a small amount of iron or chromium: an analysis showed the presence of ferrous oxide 0·7%, chromium oxide 1·1%, together with 69·01% alumina, 26·21% magnesia, and 2% silica. Under the action of heat the colour of spinel changes in much the same way as that of ruby, though at a low red-heat the stone is a dull grey instead of bluish-green; on cooling it regains its original red colour.

The specific gravity, 3·5—3·6, of spinel is rather high, though not so high as for ruby.

The size of spinel crystals is very variable; occasionally they may be as large as a walnut, while others are smaller than a pin's head, and between these two extremes they may be of any size. The two crystals represented on plate 43 show the average size. The larger crystals usually consist of a parallel aggregation of smaller individuals, and for this reason their faces are uneven and their edges rounded: only the smaller crystals are sharply developed.

Precious spinel is found as isolated crystals in the gem-gravels of Ceylon and Upper Burma; they are bounded by faces on all sides, but are often much rounded and water-worn. The crystals from Upper Burma are usually very dark in colour and those from Ceylon (plate 43, figs. 1 and 2) paler. In both these districts the mother-rock is a granular limestone, or marble, and the mineral, together with ruby, has probably been formed by the contact-action of an igneous rock-mass. Another important locality is Siam.

Blue spinel is also to be regarded as a precious spinel when it is clear and transparent; usually, however, it occurs as cloudy crystals of unattractive appearance. Transparent crystals of a deep blue colour and of the size of a pea are found in Ceylon (plate 43, fig. 3); these have the form of the rhombic-dodecahedron with its faces striated parallel to their longer diagonal, as in magnetite (text-fig. 141, p. 155), and the three-edged corners truncated by faces of the octahedron. The close relation between spinel and magnetite is expressed not only by this similarity of crystalline form, but also by the fact that in blue spinel a portion of the magnesia is replaced isomorphously by ferrous oxide (up to $3^1/_2\%$ FeO). The blue spinel from other localities is cloudy, and its colour more of a bluish-grey, whilst the crystals are much corroded. Octahedra of this kind occur embedded in limestone at Åker in Sweden (fig. 5), and large cubes with curved and corroded faces are found at Wakefield in Ottawa Co., Quebec, Canada (fig. 6).

Spinel when clear and of a good colour is one of the more valuable of precious stones; a faultless ruby-spinel of 1—4 carats would cost £5—£20, while larger stones being of great rarity are much more expensive. A spinel-ruby of unusual size, weighing $133^1/_2$ carats, is one cut in the form of a knob, and on four plane facets it bears in Persian characters the names of four emperors of the Great Mogul dynasty. As already mentioned, red spinel is often known in the trade as ruby.

Blue spinel has only comparatively recently been cut and is not often met with in jewellery. Its colour usually shows a faint tinge of green and is somewhat dusky, a good sapphire-blue colour being quite rare. A blue spinel may readily be mistaken for blue tourmaline, from which it may be distinguished by its higher specific gravity, single refraction, and absence of dichroism. A good dark blue stone costs about eight shillings per carat. Recently blue spinels have been made artificially by the same method as that devised by Verneuil for the manufacture of rubies (p. 221), and have been sold as sapphires.

Green spinel. Whilst in blue spinel a part of the magnesia is replaced by ferrous oxide, in green spinel a portion of the alumina is replaced by ferric oxide (a specimen from the Urals containing $8{\cdot}7\%$ Fe_2O_3), so that the formula becomes $MgO.(Al, Fe)_2O_3$. It also contains a small amount of copper ($0{\cdot}17\%$), to which perhaps the green colour is due. It is of a grass-green colour, and known as chlorospinel, but it is not used as a gem-stone. It occurs in chlorite-schist near Zlatoust in the Ural Mountains.

Black spinel, ceylonite or pleonaste, differs from blue spinel in containing a still larger proportion of ferrous oxide, and also sometimes in the development of its crystals. It is greenish- or bluish-black, the colour being sometimes so deep that the crystals resemble magnetite in appearance, especially when the faces are bright and smooth. The octahedron always predominates, and is present either as a simple form (plate 43, figs. 4 and 8) or in combination with the icositetrahedron $3O3$ (fig. 7 and text-fig. 174). This is distinctly a mineral of contact-metamorphic origin, occurring usually in limestone which has been altered by contact with an igneous rock. Under these conditions it is found in blocks of limestone on Monte Somma, Vesuvius; in the Fassa valley in southern Tyrol; at Warwick (figs. 7 and 8), Amity and Monroe in the state of New York. Water-worn grains are also found in the gem-gravels near Kandy in Ceylon, hence the name ceylonite: the material from this locality is richer in iron than any other black spinel, containing $20{\cdot}5\%$ of ferrous oxide, together with $57{\cdot}2\%$ of alumina, $18{\cdot}25\%$ of mangnesia, and $3{\cdot}15\%$ of silica.

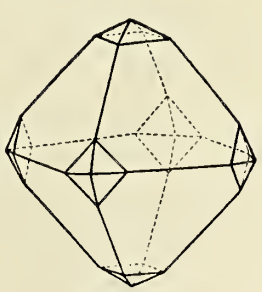

Fig. 174.
Crystal of Spinel (Ceylonite).

Pure crystals free from enclosures, especially the water-worn crystals and pebbles from Ceylon, take a very good polish, and are used in mourning jewellery, though they are of little importance.

Hercynite is a member of the spinel group in which the magnesia is almost completely replaced by ferrous oxide. It occurs as a constitution of certain gabbros, but is of limited distribution. *Picotite*, another member of the group, is more common; it contains, besides magnesia (10·3%), much ferrous oxide (25%), together with alumina (56%) and a considerable amount of chromium oxide (8%). This occurs as a constituent of rocks rich in olivine, being enclosed in the olivine. The round black grains in plate 67, fig. 6, are picotite. With an increase in the amount of chromium picotite passes into chromite (p. 157).

Zircon.

Zircon, like spinel, is a mineral the comparatively simple chemical composition of which can be interpreted in more ways than one. It contains oxide of zirconium and oxide of silicon in equal molecular proportions, and it can therefore, like spinel, be regarded as a double oxide $ZrO_2 . SiO_2$. According to another view, the compound is a salt, the zirconia being the base and the silica the acid portion; the formula is then written as $ZrSiO_4$, which express a silicate of zirconium. An analysis of a colourless zircon from Ceylon showed the presence of ZrO_2 66·71% and SiO_2 33·05%. Coloured zircon contains in addition from $^1/_2$ to 3 per cent. of iron oxide. Small amounts of thorium and other rare earths are also sometimes present.

The crystalline form is tetragonal, and the crystals, which are frequently bounded by faces on all sides, afford very good examples of this type of symmetry. The simplest form is a combination of a square prism and pyramid of the same order (text-fig. 175). This pyramid (*o*) has an angle of 123° 19′ between adjacent faces, and it is taken as the primary pyramid with the symbol *P*; the prism (*M*) is then also of the first order with the symbol ∞P. The crystals in figs. 10 and 12 of plate 43 are of this form. A steeper pyramid of the first order with the symbol $3P$ is lettered *s* in text-fig. 179, and is present in figs. 9 (on the right), 14 and 15, being in the last two larger than the pyramid *P*. Occasionally the prism faces may be very narrow or even quite absent, and we have then the simple bipyramid (fig. 21). On other crystals the prism of the second order may be present, either as narrow faces (*a* in text-fig. 176) or as the predominating form (text-fig. 177 and figs. 20 and 24); or again, it may be present to the exclusion of the first prism (text-fig. 178). Faces of an eight-sided pyramid may also sometimes occur (*x* in text-fig. 179, and fig. 13); a narrow face of the same form is seen in the lower part of

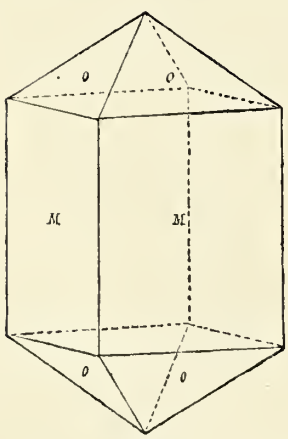

Fig. 175.

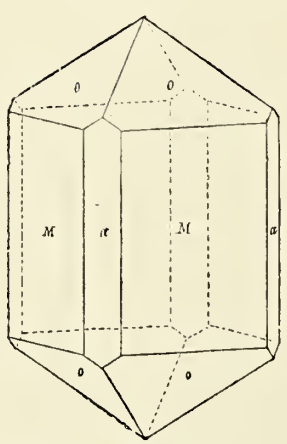

Fig. 176.

Crystals of Zircon.

the crystal in fig. 24, where it truncates an edge between the pyramid of the first order and the prism of the second order.

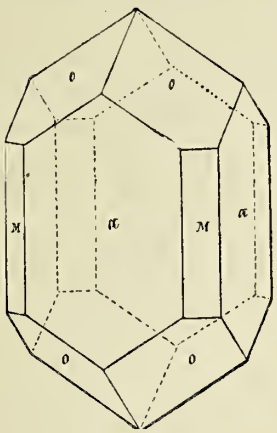

Fig. 177.

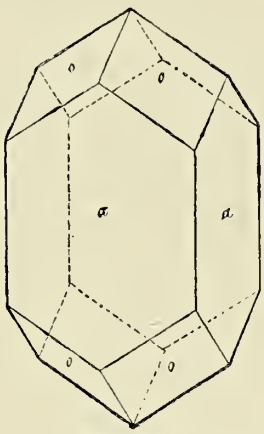

Fig. 178.

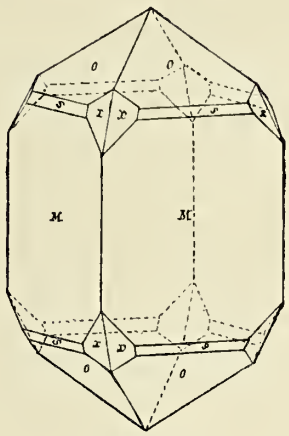

Fig. 179.

Crystals of Zircon.

Twinned crystals are rare, and they have a face of a pyramid of the second order $P\infty$ as twin-plane: in fig. 22 the forms present on the two individuals of the twin are the same as in text-fig. 175. In this mode of twinning, as well as in the habit of the crystals and the angles between the faces, there is a close similarity between zircon and rutile and cassiterite; and on this account these three minerals are often regarded as isomorphous.

Most crystals of zircon are cloudy and much fissured, being then almost opaque. Although quite hard (H. $= 7^1/_2$), such fissured crystals may readily be broken into fragments. On the other hand, clear crystals free from fissures are not so readily fractured, but these are usually rounded and with a rough surface (fig. 10 and 11). The colour is usually yellow, brownish-yellow, brown, or brownish-red to red; stones of a reddish colour being known as *hyacinth*. Other zircons may be colourless, green, rose-red, or violet, but stones of a pronounced blue colour are unknown. A few faceted stones of good colour are represented on plate 43; that in fig. 17 has much the same colour as the crystal in fig. 10, and the colour of fig. 18 is near that of fig. 11. The colour is sometimes of a very fiery hue, especially in certain brownish-red stones known as "hyacinth-topaz": in others it is more dusky, so that with a little practice it is possible to recognize zircon by means of its colour alone. The stones are not always uniformly coloured, as may be seen when they are viewed by transmitted light. The large stone shown in fig. 17 appears by reflected light to be uniformly coloured, but when it is held up in front of a window numerous very fine bands differing in colour are to be seen.

The colour of zircon is not always permanent when exposed to light and heat; for instance, zircon of a delicate rose-red from the Laacher See becomes colourless on exposure to light. Many coloured zircons are decolorized when subjected to a red-heat; and such decolorized stones may be mistaken for diamonds. A brown zircon (from Tasmania) when simply wrapped up in tinder and this ignited is decolorized, a colourless stone dropping out from the ash; it, however, does not remain colourless, and after a few months it becomes pale brownish-yellow.

The lustre of a clear zircon is adamantine in character, and approaches to that of diamond. The refractive index is high, being for the ordinary ray 1·9239 and for the extraordinary ray 1·9682, as determined on a zircon from Ceylon. The difference between

these two values shows that the double refraction is also high. Dichroism can usually be distinctly recognized with the help of the dichroscope: the stones shown in figs. 16 and 18 give rose-red and yellow images, and the green stone in fig. 19 gives yellowish-green and colourless.

A remarkable feature of zircon is presented in the very wide variations in its specific gravity. For instance, the stone represented in fig. 16 has the value 4·71, that in fig. 18 being 4·69, while that in fig. 19 has a specific gravity of only 4·22: in other stones it may be as low as 4·0. Further, the specific gravity of some of the lighter crystals may be raised to the higher limit (4·7) by heating the crystals to redness, the change in specific gravity being usually accompanied by a change in colour. These variations suggest the existence of at least three polymorphic modifications of zirconium silicate, which differ not only in their specific gravity and behaviour when heated, but also in their optical characters. Zircon is the heaviest of all precious stones, and only in its lightest varieties it is equalled by almandine.

Zircon is very resistant to chemical reagents, most acids have no action on it, and only by sulphuric acid is it very slowly decomposed. It is thus not attacked by weathering processes; when the mother-rock is broken down the zircon it contains still remains fresh and unaltered, and in this condition it is often found in river-gravels. Indeed, microscopic crystals of zircon may be found in all sands and sedimentary rocks. Such crystals of zircon can readily be separated from any ordinary sample of sand by placing it in a heavy liquid, such as bromoform (sp. gr. 2·8), in which the quartz grains will float and the heavier minerals will sink. A further separation of the heavy minerals can be made with methylene iodide (sp. gr. 3·3). In the heavy residue so obtained zircon can be recognized under the microscope by its form, which is usually like that shown in fig. 13.

As to its mode of occurrence, zircon is found embedded in granite, syenite, basalt, and other igneous rocks, and in the sands and gravels which have resulted from the breaking down of these. Most crystals are only microscopic in size, and it is at only a few localities where they are found of any appreciable size, but then often in great numbers. Attached crystals are extremely rare.

In Germany, zircon is found in the Rhenish basaltic rocks, as in the millstone lava of Niedermendig (plate 43, fig. 23), in the basalt of Burgbrohl, Unkel and the Siebengebirge; small crystals of a delicate rose-red which fades on exposure to light are sometimes to be found in the sanidine blocks of the Laacher See. Colourless crystals occur attached to the walls of crevices in chlorite-schist in the Pfitsch-thal, Tyrol, but these are rare. Large crystals are embedded in the felspar of a syenitic rock near Miask in the Ilmen Mountains, southern Urals: fig. 24 shows such an embedded crystal, and fig. 20 one isolated from the matrix. These are characterized by the predominance of the prism of the second order, and by their brown or brownish-yellow colour combined with a certain degree of transparency. Zircon also occurs in a very similar rock in southern Norway; this rock is composed of felspar, elaeolite, mica and hornblende, and is known as a zircon-syenite, though it may perhaps be more correctly described as a nepheline-syenite containing some zircon.

The largest crystals of zircon, up to nearly six kilograms in weight, come from Renfrew in Ontario, Canada (fig. 9); and large twinned crystals are found at St. Jerome, Terrebonne Co., Quebec. In the United States, zircon is more abundant, especially in North Carolina, where in Henderson county it is extracted from a decomposed granite by the ton-load and used for technical purposes. The crystal shown in fig. 12 is from Buncombe Co., North Carolina; and the brownish-black crystals in figs. 14 and 15 from

Mineville near Port Henry in Essex Co., New York. Zircon is also found in the gem-gravels and gold-washings of Brazil (fig. 21).

Ceylon is rich in zircons of gem-quality, where they occur with other precious stones in the gem-gravels of the Matura and Saffragam districts. From here come the reddish-yellow variety known as hyacinth and several other coloured zircons. Hyacinth is usually found as quite small (about the size of the crystal in fig. 23) rounded grains, while crystals of other colours, though also water-worn, are larger (figs. 11—13). Although these water-worn crystals and pebbles of zircon are rough and dull on their exterior, they yield fine stones when cut. Recently, hyacinth, similar to that from Ceylon, has been found in Tasmania; and zircon of gem-quality is also fairly abundant in New South Wales.

As to the applications of zircon, it may be remarked that the brownish-yellow hyacinth has long been used as a gem-stone, but that those of other colours have only comparatively recently been placed on the market. The stones are nearly always cut in Ceylon and India, and it is therefore difficult to obtain the rough material. Brownish stones are often decolorized by the application of heat, and are then known as "cerkonier" or "Matura diamonds", or simply as colourless zircon. These are, amongst colourless precious stones, exceeded only by diamond in their high refractive index: they may be distinguished from diamond by their higher specific gravity and by their double refraction. Coloured zircons are also readily to be distinguished from other stones of similar colour by the higher specific gravity, or if this does not suffice, as in certain garnets, by their double refraction and dichroism. The brilliant or a mixed-cut is the form of cutting usually adopted; and the stones are often cut with a considerable depth, especially in India. Owing to its brilliant lustre and rich colours, this stone in coming more and more into favour. In the trade, deep brownish-red stones with much fire are known as "hyacinth-topaz", and the green, rose-red and yellow usually by their correct name, zircon.

The price is fairly moderate. Thus, the stone from Ceylon shown in fig. 17 with a weight of 8·605 grams (42 carats) was bought for a little more than £5 (109 marks); it is, however, not quite clear by transmitted light, but it is of an unusually large size. Smaller stones are considerably cheaper, the green stone in fig. 19 costing ten shillings, and the yellowish rose-red stone in fig. 18 sixteen shillings.

Besides being used as a precious stone, zircon has certain technical applications. On account of its hardness, it is used as pivot-supports for balances. The zirconia prepared from it possesses the property of becoming incandescent when ignited; advantage of this is taken in lighting, especially for projection lanterns where a brilliant light is required. Recently, zirconia has been much used in electric arc-lamps, it giving a more steady and more brilliant light. Some samples of zircon contain thorium, which is extracted for making the mantles of the Welsbach incandescent gas-lights; the bulk of the thoria used for this purpose is, however, obtained from monazite.

Beryl.

The species beryl includes several precious stones, which, though identical in chemical composition, crystalline form, and other essential characters, are markedly different in colour; and since colour is one of the first considerations in precious stones, these colour-varieties are distingnished by special names — emerald, aquamarine, golden beryl and common beryl. To the jeweller these are different stones, differing widely in their value. Chemically, this mineral is a silicate of beryllium and aluminium with the formula

$Al_2O_3 . 3\,BeO . 6\,SiO_2$; corresponding with the percentage composition: alumina 19%, beryllia 14·1%, and silica 66·9%. A small part of the beryllia is frequently replaced by an equivalent amount of magnesia, and small quantities of alkalis and water are sometimes present, while emerald contains a little (0·3%) chromic oxide.

Crystals of beryl belong to the holohedral class of the hexagonal system, and almost without exception they are prismatic in habit. The faces of the hexagonal prism are either smooth or striated vertically, and sometimes these striations may be so deep and frequently repeated that the column approaches a cylindrical form (plate 44, fig. 11). Many crystals are bounded simply by the hexagonal prism and the basal plane perpendicular thereto (figs. 4 and 14). Pyramid planes, when present, are usually small, and they belong to hexagonal pyramids of the first and the second orders. In fig. 9 is seen a face of a pyramid of the second order (r in text-fig. 180) set over the edge of the prism of the first order. The forms and symbols represented in the accompanying text-figures (180 and 181) have already been given on p. 32 (in these figures the corresponding faces do not bear the same letters: $a = m$, $p = o$, $r = q$). Frequently the crystals show rounded or corroded terminations (figs. 6 and 8), as if they had been attacked by some solution while still in the earth's crust. Fig. 7 shows a similar appearance, but here in the central portion of the crystal.

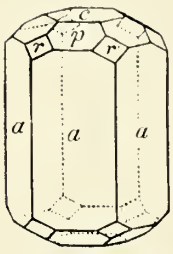

Fig. 180.

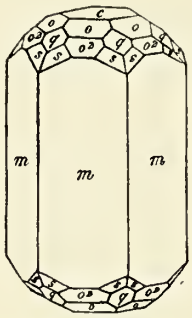

Fig. 181.

Crystals of Beryl.

There is an imperfect cleavage parallel to the base, and this is sometimes shown by a series of horizontal fissures in the crystals (fig. 14). Usually, however, this cleavage is not to be seen, and the fracture of the mineral is typically conchoidal. It is said that the ancients used fragments of beryl with their curved fractured surfaces as eye-glasses, and it has been suggested that the German word 'Brille' for spectacles is derived from the Greek name 'beryllos' for this mineral. In the interior of clear crystals of beryl there may often be seen numbers of straight striae or bands which are so delicate and fine that in a cut stone they are only visible when placed at a certain inclination to the rays of light. If these striae are present in a cut stone, we can distinguish at once between a beryl and a similarly coloured topaz. The specific gravity of beryl varies between 2·67 and 2·76, being on the average slightly higher for emerald than for aquamarine. The hardness (H. = 7½) lies between that of quartz and topaz.

Being a hexagonal mineral, beryl is doubly refracting. A chip taken off a crystal parallel to the base shows in the polariscope a uniaxial interference-figure (plate 4, fig. 1). The dichroism is distinct, and when a crystal is viewed through the prism planes with the aid of the dichroscope the two images are markedly different in colour: the crystals represented on plate 44 showed, for instance, the following pairs of colours (o for the ordinary image and e for the extraordinary image):

	o	e
Emerald (fig. 4)	yellowish-green	bluish-green.
Aquamarine (fig. 12) . . .	pale yellowish-green . . .	sky-blue.
Blue beryl (fig. 10)	almost colourless	sky-blue.
Golden beryl	gold-yellow	greenish-yellow.

The refractive power and the dispersion are both low, and the brilliancy and play of prismatic colours are correspondingly feeble; the effect of beryl as a precious stone depends rather on its fresh colour and its clearness. The refractive indices for yellow sodium-light

were determined with a bluish-green beryl from Siberia to be 1·5719 (*o*) and 1·5674 (*e*). From these values it is seen that the double refraction is also low.

According to the colour and transparency of the mineral, the varieties mentioned above may be distingnished, and these will now each be described in turn; golden beryl we shall mention together with aquamarine, since these two varieties occur together. In addition to the colours mentioned, beryl may be colourless or pale rose-red, but stones of this description are only exceptionally cut as gems.

Emerald, the most valuable variety of beryl, is distinguished by its soft grass-green or emerald-green colour. This colour is most probably due to the presence of a small quantity, up to 0·3%, of chromic oxide, a metallic oxide which imparts this same shade of green colour to glass and to a blowpipe bead of borax. The crystals have the form of hexagonal prisms and are sometimes terminated by the basal plane (fig. 4) or with the base and small pyramid planes (fig. 2): those crystals which occur embedded in mica-schist very rarely have any definite terminations (fig. 3). Transparent crystals sometimes appear cloudy in the interior, and they are frequently cracked and marked by internal fissures; large stones quite free from these fissures being extremely rare. Stones which at first appear quiet clear may after a lapse of some time show fissures. The majority of crystals are so fissured and cloudy that they are only slightly transparent. All emeralds, even the clearest, contain fluid enclosures in microscopical cavities with jagged and frayed outlines; these are so constantly present that they are a help to the recognition of a genuine emerald.

In the Ural Mountains, emerald is found embedded in mica-schist near the Takovaya stream, eighty-five kilometres east of Ekaterinburg. It occurs here in association with pale greenish beryl, alexandrite and phenacite, and was first discovered by a peasant in the year 1830. Fig. 3 shows a good, typical specimen from this locality. Most of the crystals are penetrated by the mica-schist and are fissured, cloudy and irregularly coloured; but such stones are now cut as beads. The mines remained abandoned for many years, but have recently been opened up again by "The New Emerald Company", and Uralian emeralds and alexandrites again placed on the market. The earlier workings (till 1882) yielded during a period of two and a half years 360 kilograms of emerald and 41 kilograms of alexandrite.

An exactly similar occurrence of emerald is also worked on the "Smaragd-Palfen" in the Habachthal in the Salzburg Alps. The crystals (fig. 1) average 2 cm. in length and 5 mm. in thickness, and they are frequently clouded by enclosed scales of mica.

The finest emeralds come from near the village of Muzo in the state of Bojaco in Colombia, South America (figs. 2 and 4). Here the mineral occurs with calcite and black limestone in crevices in clay-slate. The mines were long ago worked by the Peruvians, in whose possession the Spaniards found many fine emeralds. The crystals rarely exceed one or two centimetres in length, but that represented in fig. 4 measures 3 cm.

In North America, a few large crystals of emerald have been found at Stony Point in Alexander Co., North Carolina; but in these the emerald-green colour is mainly confined to an outer layer. Emeralds are also known from New South Wales, but the mining for them is confronted with too many difficulties to be profitable.

The most ancient emerald mines are those situated in Upper Egypt, on the Jebel Zabara near the coast of the Red Sea, about 120 kilometres from Um Rus and 35 kilometres from the haven of Shenu Sheik. Here, as in the Urals, the emerald occurs embedded in a dark mica-schist, and the stones are said to be of the finest quality. The extensive mines are stated to have been worked as long ago as seventeen centuries before Christ, and it must have been these so-called Cleopatra's emerald mines that yielded the emeralds worn by the ancients.

Aquamarine and Golden beryl often present a richer development of crystal faces than does the variety emerald, and their forms have already been mentioned (figs. 180, and 181). The crystals are often perfectly clear and transparent and are of fresh and bright colours. Aquamarine may range from colourless, through pale yellowish-green and bluish-green, to a decided blue shade; this range of colour is more or less represented on plate 44 in figs. 5, 12, 14, 9, 8, 10 and 11. Or again, the colour may range from pale yellow (fig. 7) to a rich gold-yellow as in the fine crystal of golden beryl not shown to its full beauty in fig. 6. These varieties are found only in cavities in granitic rocks, and are usually associated with crystals of quartz and topaz.

The principal localities are in the neighbourhood of the villages of Mursinka (figs. 6 and 7) and Shaitanka (fig. 5), near Ekaterinburg in the Urals. Large corroded crystals are found at Alapaifsk, also in the Urals. The crystals shown in figs. 8, 9, 11 and 14 are from the Adon-Chalon Mountains in the Nerchinsk district of Transbaikalia, and that in fig. 7 from the Borshchovochnoi Mountains in the same district. Good crystals of a blue colour have been found in the Mourne Mountains in Ireland (fig. 10). Colourless, reddish, greenish, and bluish crystals are also found in granite at San Piero in the Island of Elba.

In Brazil, very large crystals of aquamarine of gem-quality have been found in the district of Minas Novas in Minas Geraes, and have recently been placed on the market. These crystals are usually of a pale yellowish-green colour and are bounded by prisms and pyramids of the first and second orders, a twelve-sided pyramid and the base, the symbols of these forms being ∞P, $\infty P2$, P, $2P2$, $3P_2^3$, $0P$. Although somewhat water-worn and marked with etching-figures, these were no doubt at one time sharply developed crystals. In North America, several localities are known for aquamarine: for example, Stony Point in Alexander Co., North Carolina; Litchfield and other places in Connecticut; Albany in Maine, where golden beryl is found.

Common beryl. Under this heading may be classed all specimens, which, being cloudy or opaque and of an unattractive colour, are of no value to the jeweller. It usually occurs as rough hexagonal prisms terminated irregularly or simply by the base, and is often found embedded in quartz, as at Rabenstein in Bavaria (plate 45, fig. 1) and Metzling in Bohemia (fig. 2). The crystals are often of considerable size, and enormous crystals weighing over a ton (one weighing 2900 lbs.) have been found at Grafton in New Hampshire.

Applications of Beryl. — Transparent stones, as well as cloudy ones if only they are of a good colour, are used for cutting as gems; whilst material of poorer quality is employed for the preparation of the little-used beryllium compounds. Even by the ancients the emerald was held in high esteem as a gem-stone. We have it on the authority of Herodotus that the ring of Polycrates carried an emerald seal; and an engraved emerald belonging to this period has been discovered. It is said that Alexander caused his likeness to be engraved in emerald and that the work was done by Pyrgoteles. It is related of Nero that, owing to a weakness of the eyes, he watched the performances in the circus through an emerald. Aquamarine was also well known to the ancients under the name beryllos. According to Pliny, the most prized was the greenish beryl with a colour like that of the sea, and next to this the "chrysoberyl" (i. e. golden beryl). The greenish and bluish beryls were employed even since Hellenistic times, and especially in the Augustan age, for the finer examples of engraving, but they were also much worn as unengraved jewels. Fig. 3 of plate 40 *a* shows a scarab cut in beryl.

Beryllium Minerals.

Phenacite. This is a silicate of beryllium with the very simple formula Be_2SiO_4. An analysis of a specimen from the Urals gave beryllia (BeO) 44·7 %, silica (SiO_2) 55·14 %, and traces of alumina and magnesia. Crystals are hexagonal and are bounded by one or two six-sided prisms, the ends being sometimes rounded (plate 45, fig. 9) or provided with rhombohedral faces (text-fig. 182). In this figure the faces *m* and *a* belong respectively to the hexagonal prisms of the first and second orders, and it will be noticed that the rhombohedral faces *x* are not placed directly over the faces or edges of the prisms, as in ruby and calcite, but that the edges of intersection run obliquely. This rhombohedron is, in fact, a rhombohedron of the third order, and its faces occupy the positions of half of the faces of a scalenohedron or of one-quarter of the faces of a twelve-sided double pyramid. Phenacite therefore belongs to the rhombohedral-tetartohedral division of the hexagonal system (p. 36).

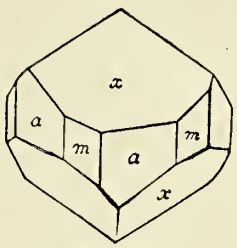

Fig. 182.
Crystal of Phenacite.

The hardness (H. = 7½) lies between that of quartz and topaz, and the specific gravity is 2·96 to 3·0. Crystals may be colourless, yellowish-white, yellowish-brown or of a pale rose-red tint, and they may be of all grades of transparency. The refractive index for the ordinary ray has been determined for Uralian phenacite as 1·6527.

Phenacite is found in the emerald mines near the Takovaya stream in the Ural Mountains, the large crystals from this locality frequently having their faces dusted over with chlorite (fig. 9). Small lenticular crystals occur with topaz and amazon-stone in granite veins at Miask in the Ilmen Mountains also in the Urals. Crystals of a short-prismatic habit are found on Mount Antero in Chaffee Co., Colorado (fig. 10), while others of a long-prismatic habit are found embedded in quartz near Kragerö in Norway. Smaller crystals are met with at Framont in the Vosges Mountains, and very rarely at Reckingen in Wallis, Switzerland, and a few other localities.

When faceted, phenacite gives a gem of considerable brilliancy, but, except in Russia, it is only exceptionally worn as a precious stone.

Euclase. Being one of the rarest of minerals, euclase is only exceptionally used as a precious stone, and the majority of the crystals that have been found are reckoned with the treasured possessions of the public collections of minerals. It contains the same chemical constituents as beryl with the addition of water, though these constituents are not combined in the same proportions: the formula is $H_2O.2BeO.Al_2O_3.2SiO_2$ or $HBeAlSiO_5$.

Crystals belong to the monoclinic system and are of prismatic habit with obliquely placed terminal faces. In text-fig. 183 the narrow prism faces are taken to be the unit prism ∞P, the wider faces then having the symbol $\infty P2$; above the former is the primary pyramid *P*, and above the latter the pyramid $2P2$; at the side are four clinodomes, $P\breve{\infty}$, $2P\breve{\infty}$, $3P\breve{\infty}$, $6P\breve{\infty}$; and behind (with parallel faces in front at the bottom) are three more pyramids and a small orthodome. Parallel to the plane of symmetry (not present as a crystal face in the figure) is a very perfect cleavage; this is represented in plate 45, fig. 13. The hardness (H. = 7½) is about the same as that of beryl, but the specific gravity (3·10) is considerably higher. The crystals are transparent, and may be colourless, yellowish-green or bluish-green; that represented in fig. 12 shows a deeper blue colour near the terminal faces than in the

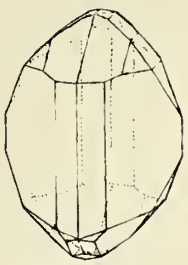
Fig. 183.
Crystal of Euclase.

lower portion of the crystal. The refractive indices fall between the values 1·65 and 1·67. Blue crystals are strongly pleochroic, the colours being dark blue and bluish-green.

The two principal localities for this mineral are represented by the crystals on plate 45. The crystal shown in fig. 12 (also plate 19, fig. 15) is from the Bakakin gold-washings in the district of the Sanarka river in government Orenburg, southern Urals. This crystal is of interest as being the first crystal of euclase found in the Urals; it was described by the Russian mineralogist General N. I. Koksharov, whose ideal representation of it is reproduced in text-fig. 183, and it was presented by Queen Olga of Württemberg to the Natural History Museum at Stuttgart.

The large crystal shown in fig. 13 (and plate 19, fig. 16) is from Boa Vista near Ouro Preto in Brazil, the same locality at which the dark yellow topazes are found. This crystal weighs 30 grams, and is bounded by the faces of two prisms ∞P and $\infty P\frac{1}{2}$, two clino-domes $2P\infty$ and $P\infty$, two pyramids P and $3P3$, and by a large cleavage face parallel to the plane of symmetry. Euclase was first discovered in Brazil and is less rare there than in the Urals. In recent years beautifully clear and sharply developed crystals have come from Brazil, but owing to their rarity they command high prices; for instance, a small, good crystal costs about £20.

A third locality is in the Grossglockner district in the Austrian Alps, where quite small, colourless crystals have been found in mica-schist.

When cut as a gem-stone, euclase displays a bright lustre and fresh colour combined with a high degree of transparency. Owing, however, to the perfect cleavage, the stone must not be dropped or knocked about, otherwise it will become fissured if not broken. Indeed, the name euclase means in Greek easily broken.

Chrysoberyl. In its chemical composition, this mineral is analogous to spinel, but in crystalline form there is no relation between these two species. Here beryllia takes the place of magnesia in spinel, the formula being $BeO.Al_2O_3$. The percentage composition corresponding with this formula is: beryllia (BeO) 19·8 per cent. and alumina (Al_2O_3) 80·2 per cent. Often, however, some iron (3—5 per cent. of ferric oxide) is present, and in the emerald-green variety a little chromic oxide.

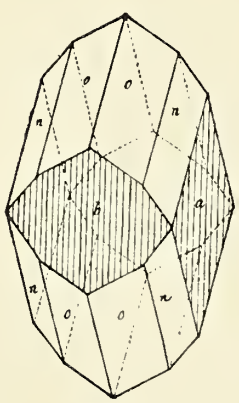

Fig. 184.

Simple crystal of Chrysoberyl.

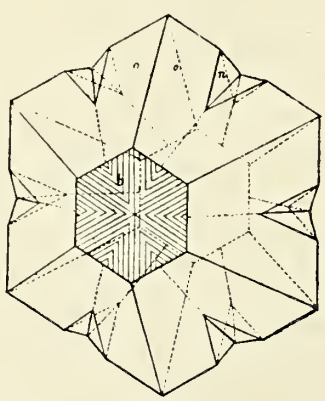

Fig. 185.

Twinned crystal (triplet) of Chrysoberyl (var. Alexandrite).

The crystals belong to the rhombic system, but, being usually twinned, they sometimes present the appearance of hexagonal crystals. The form of a simple crystal is shown in text-fig. 184, where *b* is a face of the macro-pinacoid, *a* of the brachy-pinacoid, and *o* and *n* are rhombic pyramids with the symbols P and $2P2$. Simple crystals are, however, quite exceptional, and we usually find two individuals twinned together giving a heart-shaped compound crystal (plate 45, fig. 5), or three individuals producing a pseudo-hexagonal form (fig. 8). A twin, or rather trilling, of the latter kind is represented diagrammatically in text-fig. 185, where we have an interpenetration of three crystals each of the same form as in text-fig. 184. The faces *b* of the three crystals coincide and correspond to the basal plane of a hexagonal crystal, while the rhombic pyramid

o forms the apparent hexagonal pyramid: the twinning is, however, rendered evident by the re-entrant angles formed by the faces of the rhombic pyramid *n*, and by the feather-like striations on the face *b*. In the actual crystals the faces of the pyramid *n* are not always present, and then there are no re-entrant angles, as shown in plate 45, fig. 7 and 8, and plate 19, fig. 14, these crystals having quite the appearance of hexagonal pyramids truncated by the base.

Also in its optical characters, chrysoberyl presents some striking and unusual features. The colour may be citron-yellow, brownish-yellow, asparagus-green, olive-green, or emerald-green (plate 45, figs. 4—8).

Transparent crystals of an emerald-green colour are remarkable in that they show this colour only in daylight, and are violet-red, like amethyst, in lamplight; this is best seen when the crystal is viewed through in a direction perpendicular to the striated face *b*, or in a faceted stone when the large table facet is cut parallel to the same face *b*. This peculiar variety of chrysoberyl was discovered in Russia on the very day on which the coming of age of the Czarevitch Alexander Nicolajevitch, afterwards Czar Alexander II, was celebrated, and in his honour it was named *alexandrite* by the Finnish mineralogist Nils von Nordenskiöld. Red and green being in addition the national military colours, this stone is much admired as a gem-stone in Russia, and it fetches a high price. It has been described as an emerald by day and an amethyst by night. The difference in colour is to be explained by the very strong dichroism of the mineral. To the unaided eye the green colour is especially seen in a diffused light falling on the surface of the stone, and the red colour in a glaring and penetrating light: with the dichroscope the two images are respectively deep greenish-blue and rose-red to violet. Most crystals of alexandrite are clouded by fissures and enclosed scales of black mica, and perfectly clear stones are extremely rare.

Stones of an asparagus-green or yellowish colour frequently exhibit another appearance of a special kind, namely a bluish milky band of reflected light, and as the stone is moved about this band travels over the surface (plate 45, fig. 6). This variety of chrysoberyl is known us *cymophane* or "oriental cat's-eye". The chatoyant sheen is only displayed by cloudy and translucent stones, not by those which are transparent or opaque. It is probably due to the presence of innumerable microscopically minute cavities arranged in certain directions in the interior of the crystal.

Perfectly clear and transparent chrysoberyl presents much the same range of colours as the more common mineral olivine — which it also closely resembles in crystalline form — and it is therefore often known as "oriental chrysolite". The refractive power of the mineral is very strong, the mean index of refraction being 1·748. The lustre of the cut stone is therefore high, especially as, owing to the high degree of hardness, it takes a good polish. In hardness (H. = $8^1/_2$), indeed, chrysoberyl takes a third place amongst minerals, being exceeded only by diamond and corundum. The specific gravity (3·6 — 3·8) is also high, and amongst precious stones is exceeded only by zircon, corundum, and some varieties of garnet. Few minerals are so resistant to chemical reagents as chrysoberyl: it is not attacked by acids nor fusible before the blowpipe, and is decomposed only by fused alkalis.

Chrysoberyl occurs embedded in granite and crystalline schists; with the weathering of these rocks it is set free, and it is consequently usually found in river-sands and gravels.

It is found, together with garnet and spinel, in gneiss at Marschendorf in Moravia; with tourmaline, garnet, and apatite in granite at Greenfield in Saratoga Co., New York (Plate 45, fig. 4), at Haddam in Connecticut, and at Norway and Stoneham in

Maine (fig. 5). It is also found in the gem-gravels of Minas Geraes in Brazil and of Ceylon, and in the gold-washings of the Sanarka district in the southern Urals. The stones from Brazil are mainly transparent and of an olive-green colour, whilst those from Ceylon belong to the cloudy cymophane variety. Alexandrite is found, together with emerald and phenacite, embedded in mica-schist near the Takovaya stream in the Ekaterinburg district, and it has also more recently been found in Ceylon. The stones from Ceylon exhibit at the same time the emerald-green colour of alexandrite and the chatoyant reflection of cymophane; they are, however, more olive-green in colour and are more feebly dichroic (grass-green and yellowish-pink) than the Russian.

For use in jewellery the transparent stones are usually cut in the brilliant form; and with alexandrite the stone is always mounted *à jour*, so that the difference in colour by daylight and lamplight will be the most striking. Except in Russia, alexandrite is only little used as a gem-stone, but the other varieties of chrysoberyl find more extensive application. Crystals of alexandrite are much sought after by mineral collectors and they command a high price, specimens like that shown in fig. 7 being worth several pounds.

Helvite. Although never used as a precious stone, this mineral may be considered here as an appendix to the minerals containing beryllium. An analysis of helvite from Schwarzenberg, Saxony gave: beryllia 12·03 %, manganous oxide 41·76 %, ferrous oxide 5·56 %, silica 33·26 %, and sulphur 5·05 %, corresponding with the formula $(Mn, Be, Fe)_7Si_3O_{12}S$. The sulphur is probably combined with part of the metals as sulphide, since, when acted upon by hydrochloric acid, the mineral gives off hydrogen sulphide. Helvite, in being a combination of silicate and sulphide, thus shows a relation to lazurite.

The crystals (plate 45, fig. 3) have the form of the regular tetrahedron; they are sulphur-yellow or honey-yellow with little transparency. They are always quite small, rarely exceeding 4 mm. along their edges. The specific gravity is 3·1—3·3, and the hardness rather over 6. The best crystals are found embedded in gneiss at Schwarzenberg in Saxony, the locality of the specimen figured in plate 45.

Topaz.

The name topaz is applied by the jeweller to transparent gem-stones of a yellow colour, but only few of these really belong to the mineral topaz: the majority of them are varieties of quartz, whilst others are corundum. The true topaz contains the constituents of both these minerals, namely the silica of quartz and the alumina of corundum, combined in equal molecular proportions, but in addition to these it also contains fluorine, the mineral being a fluo-silicate of aluminium. The fluorine may be considered to replace part of the oxygen, and the formula may be written as $4\,Al_2SiO_5 + Al_2SiF_{10}$, or more simply as $(AlF)_2SiO_4$. Furthermore, a portion of the fluorine may sometimes be replaced by hydroxyl (OH), so that the mineral is not constant in composition. An analysis of topaz from Schneckenstein in Saxony gave: silica 33·53 %, alumina 56·54 %, and fluorine 18·62 %.

Crystals of topaz belong to the rhombic system, and they are invariably prismatic in habit. Faces of at least two prisms are always present, and, according to the relative length of these faces the crystals may be of a short or long prismatic habit. The prism faces are usually striated vertically, and the angles between them are $124\frac{1}{2}^0$ for one prism and $86\frac{3}{4}^0$ for the other. The crystals are provided with different faces at their upper

ends, according to the locality at which they are found, and, being usually attached to the matrix, they only rarely show terminal faces at the other end. The simplest combination is that of the two prisms with a pyramid (plate 46, figs. 9 and 10); in other crystals a large basal plane is present, together with pyramids and dome faces (figs. 1, 2 and 6); or again, the base may be absent, and the crystals terminated by a steep dome (fig. 11), or a steep dome and steep pyramid faces (fig. 12).

These several modifications are better illustrated by the accompanying text-figures, three of which are drawn with terminal faces at both ends. In all of them we see the two prisms $M = \infty P$ and $l = \infty P 2$; in text-figs. 186 and 189 these are about equal in size, while in the other two figures l is much larger than M. In combination with these prisms we have in text-fig. 186 the rhombic pyramid $o = P$, as in plate 46, figs. 9 and 10. In text-fig. 187 the pyramid (here a more obtuse pyramid $^1/_2 P$) is much smaller,

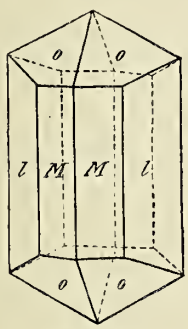

Fig. 186.

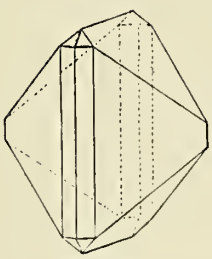

Fig. 187.

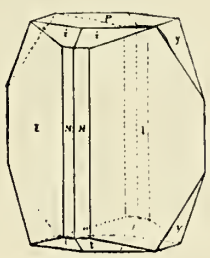

Fig. 188.

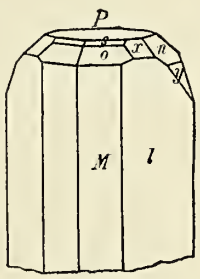

Fig. 189.

Crystals of Topaz.

From Brazil. From Nerchinsk, Siberia. From Mursinsk, Urals. From Schneckenstein, Saxony.

and in addition we have a large brachy-dome $2 P \breve{\infty}$, as in the attached crystals in fig. 11 of the plate. In text-fig. 188 the base $P = 0 P$ is present, and the pyramid ($^1/_3 P$) is still flatter (fig. 6, plate 46). Finally, in text-fig. 189, there are above the primary prism M two pyramids $o = P$ and $s = {}^2/_3 P$, above the prism l there is the pyramid $x = \frac{4}{3} P 2$, to the right two brachy-domes $y = 4 P \breve{\infty}$ and $n = 2 P \breve{\infty}$, and at the top the basal plane $P = 0 P$; these being the forms shown by the crystals in figs. 1 and 2 of the plate.

The colouring of topaz is very variable (see plate 46); crystals may be perfectly colourless, pale yellow, dark yellow, brown, pink, violet-red, bluish-green, or blue. When transparent, the mineral has a brilliant glassy lustre, although the refractive power and dispersion are not specially strong. The mean refractive index is 1·612 for red light, 1·616 for yellow, and 1·621 for blue, so that topaz is more strongly refracting than quartz and beryl. The colours are often not permanent when exposed to light and heat: some crystals fade on exposure to daylight, and the yellow Brazilian topaz (fig. 10) when subjected to a moderate heat (over 300° C.) becomes a delicate rose-red, not quite so deep as of the crystal in fig. 9, the colour of which is probably original.

The dichroism of topaz, though distinct, is never very strong. A colourless water-worn pebble when held before the dichroscope shows pale green and pale rose-red images, but these colours are so very faint that it is only by their contrast that they are distinguishable. The pale yellow Saxon topaz gives colourless and pale greyish-yellow images, while the darker yellow Brazilian topaz gives colourless and pale yellow in a thin ($^1/_2$ cm.) crystal, and pale yellow and dark wine-yellow in a thicker (2 cm.) crystal. A Brazilian topaz, made pink by heating, shows pale violet-red and a pale yellowish-red when viewed

through the prism faces (as with the preceding crystals); but when viewed through the basal plane with a greater thickness of material it shows rose-red and yellow colours in the dichroscope. The naturally-occurring pink crystals from Brazil are more strongly dichroic than the "burnt" pink topaz, the two images being here yellow and violet. The rose-red crystals from the Sanarka River give reddish-violet and rose-red. Since topaz is rhombic the absorption of light is different along the three axes, as may be readily seen when a crystal is examined in different directions with the dichroscope. A yellowish-red crystal, which had not been heated, from Brazil gave the following pairs of colours:

in the direction of the macro-axis *b*: dark yellow and rose-violet,
in the direction of the brachy-axis *a*: rose-violet and red,
in the direction of the vertical-axis *c*: red and dark yellow.

Topaz possesses a perfect cleavage in one direction, this being parallel to the basal plane; and for this reason crystals when broken away from the underlying matrix almost always show a smooth and bright cleavage face, as may be seen in figs. 1, 2, 8 *a* and *b*, 9 and 10. In fig. 12 the crystal shows a cleavage crack across the middle. Cleavage flakes of topaz when examined in convergent polarized light show the interference-figure of an optically biaxial crystal (plate 4, figs. 3 and 4).

The hardness of topaz is between that of quartz and corundum, and figures as No. 8 in the scale. The specific gravity of 3·56 is almost exactly the same as that of diamond. The mineral is very resistant to acids and to weathering agents, so that it scarcely ever shows signs of decomposition. In some crystals, cavities partly filled with liquid carbon dioxide are to be observed: and when such crystals are heated they often burst.

Although most frequently found as well-developed crystals, topaz also occurs as columnar masses with a divergent grouping, as in the variety known as pycnite, and as compact masses to which the name pyrophysalite is applied.

Crystals of topaz occur either in granitic rocks, often in association with tinstone, or in the cavities of recent volcanic rocks such as rhyolite (fig. 12). In both cases the mineral has been deposited by hot solutions or vapours which have accompanied the eruption of the igneous magma. With the weathering of these rocks the more stable topaz is set free, and it is then found as rolled crystals and pebbles in river-gravels.

The more important localities are the following. Pale wine-yellow crystals of the characteristic habit shown in text-fig. 189 and plate 46, figs. 1—3, are common at the Schneckenstein near Auerbach in Saxony. Here they occur, together with crystals of quartz, attached to the surface of a breccia consisting of fragments of a tourmaline-rock cemented together by quartz and topaz, the whole being known as a topaz-fels or topaz-rock; enveloping the crystals is often some white or yellowish steatite, as shown on the right in fig. 3. Small, colourless crystals of topaz are found in the deposits of tin-ore at Ehrenfriedersdorf and Altenberg in Saxony, Zinnwald and Schlaggenwald in Bohemia, and in Cornwall; and similar crystals are met with in cavities of the granophyre of the Mourne Mountains in Ireland.

In Russia, topaz occurs in cavities in granite at the same places that beryl is found, and sometimes magnificent, large and clear crystals are met with. On Mount Makrushi at Alabashka, near Mursinsk in the Ekaterinburg district of the Urals, beautiful, pale blue crystals (figs. 6 and 7) and more rarely colourless crystals (fig. 5) are found: these are terminated by a large basal plane, and large brachy-dome and pyramid faces. They are accompanied by fine crystals of felspar (fig. 7), reddish-white lithia-mica, albite, and smoky-quartz (fig. 5). On the eastern side of Lake Ilmen, in the neighbourhood of the smelting works of Miask in the Ilmen Mountains (southern Urals), small, colourless and perfectly developed crystals are found, together with green felspar (amazon-stone), phenacite

and black mica. In the Bakakin gold-washings on the Sanarka River, Government Orenburg, rose-red and violet-blue crystals are found (fig. 8 *a* and *b*), which resemble the Brazilian both in colour and form, being terminated by the pyramid. In the same district, rose-topaz has also been found in quartz-veins, together with green tourmaline and a green mica known as fuchsite.

Fine crystals of topaz are also met with in eastern Siberia, but, whilst in the Urals the crystals usually occur singly in cavities, they are here united in druses, as shown in fig. 11, representing a specimen from the Adon-Chalon Mountains in the Nerchinsk district of Transbaikalia. Here the white crystals are terminated by the large brachy-dome $2\,P\infty$ without the basal plane, and they are accompanied with crystals of smoky-quartz and beryl. Topaz crystals of a similar form, but yellowish or bluish in colour, are also found in the neighbourhood of the Urulga River in Nerchinsk; these often show signs of corrosion (fig. 4), and they are distinguished by their exceptional beauty of colour and transparency and by their large size; crystals measuring 28 centimetres in length and 16 cm. in thickness have been found here. The localities are situated in the Borshchovochnoi and Kuchuserken ranges, but there is much confusion in the statements of the exact places where the crystals are found. As Koksharov has pointed out, this is due to the great similarity of the crystals from the several localities, and to the remoteness of this region. The peasants collect the variously coloured stones, such as topaz, beryl, etc., from several spots in the mountain ranges of the Nerchinsk district and bring them to the town of Nerchinsk for sale. They are there bought up by dealers, who attach more importance to the transparency, perfection of crystalline form or value for cutting as gems than to any exact statement of locality, and are sold again at fairly high prices in Irkutsk, Ekaterinburg and even at the fairs of Nizhniy-Novgorod, from whence they pass into eastern Russia and the rest of Europe. The statements in mineral collections of the exact locality for specimens of topaz, beryl, and other minerals from this far-off region must therefore always be considered as doubtful.

In Brazil, crystals of pale yellow, dark yellow, and pink topaz (figs. 9 and 10) are found in the neighbourhood of Ouro Preto in the state of Minas Geraes; they occur in nests, together with quartz, rutile, and haematite, in a rock which has been completely altered to clay; and sometimes the topaz crystals are found embedded in the quartz. The colourless and blue topazes of Brazil are found only in the gem-gravels, together with diamond, beryl, chrysoberyl, rock-crystal, andalusite, and other minerals, in the Minas Novas district. The colourless pebbles are known locally as "pingos d'agoa" (drops of water). Very similar to the yellow Brazilian topaz, both in form and colour, are crystals, often of considerable size, from Mugla in Asia Minor.

In Mexiko, beautiful, water-clear topaz crystals are met with in the tin mines of San Luis Potosi and Durango; and in the United States, pale yellow and brownish-yellow crystals are found in the cavities of a porphyritic rock (rhyolite) at Nathrop in Colorado (fig. 12). The crystal shown in this figure is remarkable in being bounded by faces (steep pyramids and brachy-dome) at the two ends. Colourless, pale blue or greenish crystals are also found at Stoneham in Maine, and here large, opaque crystals weighing as much as 10 to 20 kilograms have been met with. Fine, water-clear crystals of considerable size are known from Otani-yama in Japan, and colourless and pale blue material suitable for cutting is found in the New England district in New South Wales. Other localities might be mentioned, but from those which have been stated we see that fine crystals of topaz is of fairly common occurrence.

The topaz which is made use of for gem purposes comes almost exclusively from Russia, Brazil, and Australia. The parcels usually consist of broken pieces and are often mixed with beryl.

Colourless topaz is known as precious topaz and also as "pingos d'agoa" or drops of water; it is cut in the brilliant form and mounted *à jour*. A few years ago a large number of perfectly water-clear stones were placed upon the market, but now they are again rather rarer. Such stones, although very bright and clear, have not the lustre and brilliancy of the diamond, in comparison with which they appear dull. They cannot be distinguished from diamond by the specific gravity, but are readily distinguished by their double refraction and refractive indices, the latter being readily determined with the aid of a refractometer. A two-carat stone costs about fifteen shillings. Yellow topaz is now not much used for cutting, and the majority of yellow stones which are sold as topaz are really quartz ("golden topaz" and "Spanish topaz"); it is usually converted by heating into the more valuable rose-topaz. This is often very similar to pink tourmaline, but the two can be distinguished by their dichroism and better still by their specific gravity: in pure methylene iodide topaz sinks and tourmaline floats. In recent years this pink "burnt" topaz has again come into favour for jewellry. The violet-red crystals from the Sanarka River are much too rare to be of any importance as gems. Bluish-green and blue topaz is almost always sold in the trade as beryl or aquamarine, and indeed by mere inspection it is not easy to distinguish the two stones. They are, however, easily distinguished by their specific gravity, beryl floating in methylene iodide or in bromoform, whilst topaz sinks. A mineral collector will, as a rule, have to pay more for a crystal of beryl than for a crystal of topaz, but for gem purposes the two minerals are of about equal value.

Garnet.

The name garnet is applied to a group of minerals which, though identical in crystalline form and of the same chemical type, vary considerably in chemical composition; in other words, they are members of an isomorphous group. They are all silicates, and several of the varieties contain calcium together with either alumina, ferric oxide, or more rarely chromic oxide; other varieties contain alumina together with either ferrous oxide, magnesia, or more rarely manganous oxide. There are thus two main groups — the lime-garnets and the alumina-garnets (lime-alumina-garnet being included in both):

Calcium-aluminium-garnet $Ca_3Al_2Si_3O_{12}$. Iron-aluminium-garnet . . . $Fe_3Al_2Si_3O_{12}$.
Calcium-iron-garnet . . . $Ca_3Fe_2Si_3O_{12}$. Magnesium-aluminium-garnet $Mg_3Al_2Si_3O_{12}$.
Calcium-chromium-garnet $Ca_3Cr_2Si_3O_{12}$. Manganese-aluminium-garnet $Mn_3Al_2Si_3O_{12}$.

The actual percentage composition of garnets belonging to the more important varieties, which will be described in more detail further on, is given in the following table of analyses: —

	SiO_2	Al_2O_3	Fe_2O_3	Cr_2O_3	FeO	CaO	MgO	MnO
1. Almandine: Zillerthal, Tyrol	39·12	21·08	6·00	—	27·28	5·79	—	0·80
2. Hessonite: Ala, Piedmont	38·13	18 35	7·17	—	—	35·40	0·02	0·13
3. Pyrope: Krems, Bohemia	40·45	19·67	4·05	2·60	6·90	5·78	20·79	—
4. Demantoid: Syssersk, Urals	35·56	0·57	30·80	—	0·64	33·05	0·16	—
5. Uvarovite: Bissersk, Urals	36·93	5·68	1·96	21·84	—	31·05	1·54	—

It will be seen that Nos. 2, 4, and 5 are essential lime-garnets, 2 being a calcium-aluminium-garnet, 4 a calcium-iron-garnet, and 5 a calcium-chromium-garnet, whilst 1 is an iron-aluminium-garnet, and 3 a magnesium-aluminium-garnet. Further, it will be noticed that none of them correspond exactly in composition with the pure compounds, but are mixtures of several of these.

Before passing to a description of the more important varieties, we will now enumerate those characters which are common to all the varieties of garnet.

All garnets crystallize in the cubic system, and the simplest and at the same time the commonest form of crystal is the rhombic-dodecahedron, which form is on this account sometimes called the garnetohedron. In plate 47 the crystals shown in figs. 1, 5, 7, 8, 11, and 15 present this form. Less frequent as a simple form is the icositetrahedron with the symbol 2 O 2, as shown in figs. 6 and 12. The combination of these two simple forms is to be seen in fig. 13 (text-fig. 190) and less distinctly in fig. 9. In addition to these, a hexakis-octahedron 3 O $^3/_2$ is sometimes present as narrow faces truncating the edges between the rhombic-dodecahedron and the icositetrahedron (text-fig. 191). A completely developed crystal presenting this combination of three forms is bounded by 84 (= 12 + 24 + 48) faces. Forms other than those mentioned are of rare occurrence on garnet, and twinned crystals are not known.

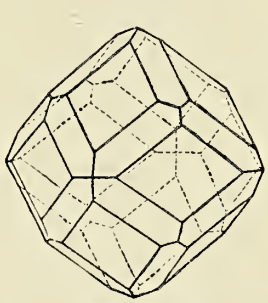

Fig. 190.

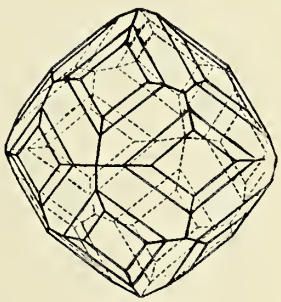

Fig. 191.

Crystals of Garnet.

The hardness of garnet is about the same as that of quartz. There is no distinct cleavage, and the crystals are often traversed by irregular fissures. The specific gravity varies between wide limits, 3·4—4·3, corresponding with the variations in chemical composition; the lower limit being 3·4, all varieties of garnet sink in methylene iodide.

As may be seen by a glance at plate 47, the range of colour presented by garnet is very considerable, blue being the only colour not represented; white or colourless garnet is quite rare. Sometimes the crystals are built up of alternately lighter and darker layers, as may be seen when such a crystal is broken open (fig. 3) or in a thin section; this is especially the case in the variety melanite.

Being a cubic mineral, garnet is not dichroic; but in opposition to this rule it is sometimes doubly-refracting, though the anomalous double refraction is never so strong as to allow of a confusion between garnet and other minerals. The refraction is strong in all varieties, the refractive index varying from 1·74 to 1·82. The dispersion is also strong, though, owing to the intense coloration of the mineral, this is not conspicuous.

Garnets occur embedded in rocks of many different kinds, for instance, granite, phonolite, serpentine, crystalline schists, and limestones; and they also occur attached to the walls of crevices in crystalline silicate rocks. As a rule, each kind of garnet is confined to a particular class of rock. We now proceed to a description of the different varieties and the mode of occurrence of each.

Almandine is a dark-red garnet which in chemical composition is an iron-aluminium-garnet. The colour often shows a tinge of bluish-violet, though it may also be carmine-red or yellowish-red. By the dealer in precious stones the name almandine is more particularly applied to garnets of a bluish-red colour, but by the mineralogist the name is applied to

all iron-aluminium-garnets whatever be their colour. Almandine is the heaviest of all garnets, the specific gravity being 4·3, a value which amongst precious stones is exceeded only by some specimens of zircon. The rich colour of the stone is sometimes combined with perfect transparency, but usually almandine is fissured and only slightly transparent. It is the commonest of the garnet varieties, and is indeed a widely distributed mineral, occurring more particularly in the crystalline metamorphic rocks (gneiss, mica-schist, chlorite-schist, and granulite). A cloudy and fissured crystal isolated from the rock is shown in plate 47, fig. 11, and rather clearer crystals are represented in figs. 12 and 13. The first of these is a rhombic-dodecahedron, fig. 12 an icositetrahedron, and fig. 13 a combination of these two forms (text-fig. 190).

The localities at which almandine is found are so numerous that only a few of the most important can be mentioned in this place. In Europe, large crystals are abundant in the chlorite-schist of the Granatenkopf in the Oetzthal Alps (plate 47, fig. 11), as also in the Zillerthal in the Tyrol, and in the St. Gotthard district. Smaller crystals are found in the Riesengebirge, Black Forest, and Odenwald; at Fahlun in Sweden; at Mursinsk, Miask, Zlatoust, and other places in the Ural Mountains; and in fact in all mountainous districts where crystalline rocks abound. Specially fine crystals occur embedded in mica-schist at Fort Wrangell in Alaska (fig. 13) and in Greenland (fig. 12). Material of gem-quality is mined in Rajputana, Jaipur, and other parts of India, and is also obtained from the gem-gravels of Ceylon. In recent years a garnet which appears to be almandine has been obtained from German East Africa: it comes into the market as beautifully-clear, platy fragments showing either the bluish-red colour of alamandine or the blood-red of pyrope, and it is strongly doubly-refracting.

Almandine and other closely allied garnets have been used as precious stones since very early times. The old names ἄνθραξ and carbunculus have reference to the red colour, similar to that of a glowing coal; and the Syriam garnet, which probably has its name from the ancient trade centre in Pegu (although garnet is not found at that place), was probably a similar stone. The bluish-red stones, or almandine proper, are sometimes known as oriental garnet, and in colour these are occasionally distinctly violet; but as this colour does not show to advantage in lamplight such stones are of less value. It was much used in Grecian and Roman times for engraved gems. Almandine when of a brownish-red colour is known as vermeille garnet. The garnet from German East Africa has been incorrectly known in Bohemia (where it was at first cut in large quantities) as "Fashoda garnet". Apart from the purity, clearness, and size of the stones, the value of almandine depends largely on its colour, being greater when this approaches more nearly to a pure ruby-red, and less when yellowish-red and violet.

Hessonite, or cinnamon-stone, has a honey-yellow, yellowish-red, or hyacinth-red colour (plate 47, figs. 1 and 2), similar to that of cinnamon-oil. In chemical composition it is a calcium-aluminium-garnet; and it has the lowest specific gravity (3·4—3·6) and refractive index (1·74 for red light) of all the garnets. It is found as crystals, together with crystals of diopside and chlorite, attached to the wall of crevices in serpentine in the Ala valley in Piedmont (fig. 4), the crystals from this locality having the form shown in text-fig. 191. The material used in jewellery comes mainly from Ceylon, sometimes as simple rhombic-dodecahedra (fig. 1), but more usually as irregular, water-worn fragments, which are found together with hyacinth (zircon) and other minerals in the gem-gravels. It is indeed often confused with hyacinth, from which it may be distinguished by its lower specific gravity and its single refraction; in value the two stones are about equal. Hessonite was much admired at the time of Alexander the Great, and it is still in high favour.

Here we may also mention another variety of calcium-aluminium-garnet, which, though of no importance as a precious stone, is frequently found as well-developed crystals. This is known as *grossularite* or "gooseberry-stone", on account of its pale green colour in some specimens (fig. 5 and 6). The crystals shown in these two figures are respectively a rhombic-dodecahedron and an icositetrahedron. Such crystals are found, together with idocrase (plate 49, figs. 1—3), near the junction of the Achtaragda and Wilui Rivers in eastern Siberia. Grossularite is typically a mineral of contact-metamorphic origin, occurring embedded in limestones where these have been altered by contact with an igneous rock. Under these conditions it is found as white and brownish-red crystals at Auerbach in Hesse, and with magnetite at Dognacska in Hungary. A beautiful rose-red garnet occurs embedded in limestone at Xalostoc in Mexico (fig. 7). Other localities for grossularite are Gleinitz near Jordansmühl in Silesia, Monzoni in southern Tyrol, Rumford in Maine, etc. Large crystals, sometimes with limestone attached to them, have been found in sand beneath the cathedral at Breslau, but where these came from originally is not known.

Pyrope is perhaps the best known of the gem-varieties of garnet. In colour it is blood-red to a brilliant fire-red, the name pyrope meaning in Greek fiery. The name has thus the some meaning as carbuncle, and formerly the two varieties were doubtlessly confused with one another; there is, however, not only a difference in colour between them, but also a difference in their chemical composition and mode of occurrence. Pyrope is a magnesium-aluminium-garnet, but also contains some iron and chromium (2—6% chromic oxide). It occurs embedded in olivine-rocks or in the serpentines which have been derived from the alteration of such rocks (plate 47, fig. 16); and on the complete breaking down of the serpentine the pyrope is set free, being then found loose in the soil or in sands. Crystals are extremely rare, the mineral usually having the form of grains, which rarely exceed a centimetre in diameter and are usually only a few millimetres. The specific gravity of 3·7—3·78 is considerably less than that of almandine.

Since early times the best known localities for pyrope are in the north of Bohemia, and for this reason it is often known as Bohemian garnet. The garnet-bearing district, with an area of seventy square kilometres, lies on the southern slopes of the Mittlegebirge (Midland Mountains) and to the north of the Eger river, that is, to the west of Trebnitz and the south-west of Leitmeritz and Meronitz, and with a small portion in Saxony (the specimen shown in plate 47, fig. 16, being from Zöblitz in Saxony). About one-tenth of this district is rich in garnet The garnets are accompanied by zircon, ceylonite, corundum, tourmaline, olivine, opal, and other minerals. Originally the grains of pyrope were embedded in an olivine-rock which become altered by weathering to serpentine; later this material was broken up by volcanic eruptions giving rise to a volcanic tuff; still later this tuff was removed by ice action, and now the garnets are mainly found in a layer of glacial drift having a thickness of up to seven metres. Some of this material has been again sorted by running water, and garnets are consequently also found in the beds of the existing streams, so that they have been transported on no less than three separate occasions from their place of origin. The garnet is won by sinking pits in these secondary deposits. Most of the stones obtained are so small that 500 or more do not weigh more than a lot (= $16^2/_3$ grams, or rather less than $^1/_2$ oz. avoirdupois), while stones the size of a pea are quite rare. Since the stones are all of the same quality as regards colour and clearness, their value increases rapidly with the weight of individual stones, the value of the smaller material being little more than the cost of production.

The garnet industry of Bohemia, which has its centre at Turnau on the Isar, is in many respects similar to the agate industry at Idar and Oberstein in Germany.

At both the greater part of the population is engaged in the gem-cutting industry and its allied branches, and in both the work was started upon material found in the vicinity, but is now extended to imported stones of all kinds. Owing to the lower rate of wages in Bohemia, there is a keen competition between these two centres of the gem-cutting industry.

In beauty, as well as in the size of the stones, the Bohemian pyrope is surpassed by the garnet found in association with the diamond in South Africa. This also is a chromiferous magnesium-aluminium-garnet, and it is known in the trade as "Cape ruby". It shows a pure and glowing carmine-red colour combined with a brilliant lustre and strong fire, and it is the most valuable of the garnets. Like the Bohemian pyrope, it is also found only as angular grains; and it is associated with a paler red pyrope and the other minerals mentioned under diamond (p. 210) in the "blue ground" of the dry diggings and in the sands of the river diggings, though only in small amounts.

Demantoid and **Melanite.** These two varieties of garnet though differing widely in colour — the former being green and the latter black — are essentially the same in chemical composition, being calcium-iron-garnets, though melanite contains in addition some titanium dioxide. Both of them, together with some other varieties, are included under the mineralogical name andradite.

Demantoid is transparent with a pale yellowish-green to deep emerald-green colour, and its specific gravity is 3·83. It is found as grains and kidney-shaped nodules in crevices in a serpentine-like rock or in auriferous sands in the Ural Mountains. Colourless to pale green pebbles are found in the gold-washings near Nijni-Tagilsk, and beautifully coloured grains in the serpentine near the Bobrovka stream in the Syssersk district. Recently large quantities of this material have been placed on the market, and it has largely increased the use of transparent green stones in jewellery. When well cut, the stones display a brilliant lustre and a strong fire, the fine appearance being but poorly represented in fig. 17, plate 47. Those of a darker green colour may perhaps be mistaken for emerald, but they are readily distinguished by the specific gravity; in bromoform or methylene iodide demantoid sinks, whilst emerald floats: further, emerald is doubly refracting and dichroic, whilst demantoid is not.

Melanite is black and opaque and always forms well-developed crystals with the rhombic-dodecahedron and the icositetrahedron in combination (plate 47, fig. 9, and text-fig 190). Unlike other garnets, melanite occurs as a constituent of certain volcanic rocks (phonolite, leucitophyre), the small black crystals being visible to the unaided eye; or as seen in thin sections of the rock under the microscope they usually show six-sided outlines and an alternate banding of lighter and darker layers. It is found in the volcanic rocks of the Kaiserstuhl near Freiburg in Baden, at Rieden near the Lake of Laach, and at Frascati in the Albanian Hills near Rome (fig. 9).

Calcium-iron-garnet is also found as beautiful green and brown crystals at Schwarzenberg and Breitenbrunn in Saxony; and nodules similiar to the Uralian demantoid occur in serpentine at Dobschau in Hungary. Green calcium-iron-garnet is, in fact, of common occurrence as a secondary mineral in association with serpentines, as, for example, a variety known as topazolite from the Ala valley in Piedmont, and the small crystals from the neighbourhood of Dillenburg in Nassau.

Uvarovite or calcium-chromium-garnet, is very similar in appearance to the emerald-green demantoid, but it always occurs as crystals, being found as small, sharply-developed rhombic-dodecahedra on the surface of chromic iron-ore. In plate 47, fig. 10, the underlying chromite has been oxidized on the surface to a yellowish-brown alteration product. Uvarovite has a specific granity of 3·42, and it contains about 22% of chromic

oxide. Crystallized specimens are found near the smelting works of Bissersk in the northern Urals (fig. 10), and occasionally clear crystals have been cut, but these are too small and rare for the mineral to be of any importance as a precious stone.

Tourmaline.

Tourmaline is of special interest on account of its crystalline form and its physical characters, and it is at the same time of importance as a precious stone and as a rock-forming mineral. The name is a corruption of the Cingalese word turamali, the mineral having been brought under this name from Ceylon by the Dutch in 1703: previous to this it was known in Germany as schorl, a name now usually restricted to the black, fibrous varieties.

The crystals are prismatic in habit and often show a six-sided prism in combination with a three-sided prism (plate 48, fig. 11, and text-fig. 192); and according to the relative sizes of these two prisms the crystals are nine-sided or triangular in cross-section. Since the crystals are usually attached by one end to the matrix (figs. 1 and 13), terminal faces are developed only at the free end, but the presence of the triangular prism is alone sufficient to prove that tourmaline is rhombohedral-hemimorphic (p. 35). When the crystals are doubly terminated, which is comparatively rare, there is a different development of faces at the two ends, as clearly shown in text-fig. 192. In this figure l is the triangular prism of the first order, and s the hexagonal prism of the second order; at the upper end, the three faces P form a triangular pyramid truncating the edges of a more acute triangular pyramid o; while at the lower end we have the three parallel faces P (which together with the faces P at the top form a rhombohedron) the edges of which are truncated by narrow faces of an obtuse triangular pyramid n. Taking P to be the primary pyramid with the Naumannian symbol $+R$, o is then $-2R$, $n = -\frac{1}{2}R$, $s = \infty P 2$, and $l = \frac{\infty R}{2}$. The angle between the faces of the primary form is $133^0\ 10'$; and when this has been determined with the aid of the contact goniometer, the other faces can be determined by noticing which edges are truncated.

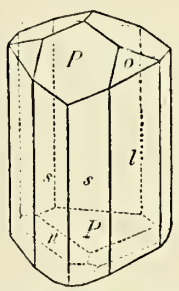

Fig. 192.
Crystal of Tourmaline.

Of the crystals represented in plate 48, fig. 1 shows a combination of the hexagonal prism (s) and the primary pyramid (P). In figs. 3 and 11 to the same forms are added narrow faces of the triangular prism (l). In fig. 5, with the top of the crystal directed towards the observer, we have the primary form $+R$ truncated by narrow faces of the next obtuse pyramid $-\frac{1}{2}R$, and in the centre the basal plane $0R$. In fig. 6 we see the forms $s\ P\ o$, and in fig. 12 $s\ l\ P\ o$, while in fig. 2 the crystal is terminated by the basal plane alone. Occasionally the crystals display an extremely rich development of faces, many more than represented in the figures here given.

Even when a crystal of tourmaline is broken at its two ends, as in fig. 17, the hemimorphic character is betrayed by its peculiar electrical behaviour. When a crystal of tourmaline is subjected to changes of temperature, either during cooling or heating, it develops an electrical charge on its surface, and it then has the property of attracting to itself small and light objects. This pyro-electrical character of

tourmaline was first noticed by the Dutch, at the time they brought the mineral from Ceylon: crystals which had fallen into the hot ashes of a turf fire were seen to have particles of ash adhering to them. For this reason the mineral was called *aschtrekker*, meaning in Dutch ash-drawer. It must further be remarked that the two ends of the crystal become charged with electricity of opposite kinds, one end being positively and the other negatively charged. This may be most conveniently demonstrated by a method devised by Professor Kundt: a crystal is heated in an oven to a temperature not exceeding 120° C., it is quickly passed through the flame of a spirit-lamp to remove any electrical charge that may to present, and is then placed on a dry surface and allowed to cool; during the cooling a dry mixture of flowers of sulphur and red-lead is dusted over the crystal through a fine sieve, when the sulphur will be attracted to the positively charged end and the red-lead to the negatively charged end of the crystal, and the two ends will be so coloured yellow and red. The best kind of material to use for this experiment is a dark green Brazilian crystal such as shown in fig. 17. According as the temperature of the crystal is rising or falling so will there be a difference in the electrical charges; the end which becomes electrically negative during cooling will become positive during a rise in temperature; this end of the crystal is called the analogous pole, and the other end is then the antilogous pole. We have here an excellent example of a connexion between the form of a crystal and its physical characters; and in all hemimorphic crystals (for example, hemimorphite, p. 131), where we have an axis with a different development of faces at its two ends, that axis is a polar electrical axis.

The optical characters of tourmaline also present certain remarkable features. In the first place, the range of colours is very extensive, almost every shade of colour being represented, and often the fine colour is combined with perfect transparency and clearness. Some crystals are colourless or so faintly tinged with pink, green, or blue that the colour is only noticeable in thicker layers: and with increasing depth of colour there may be a gradual passage from delicate rose-red to deep ruby-red, from a soft green to a dusky green, from a pale blue to intense indigo-blue or bluish-green of various shades, or from a light yellowish-brown to black. In many instances different parts of one and the same crystal are differently coloured. For example, the larger portion of a prismatic crystal may be pale coloured and its free end dark coloured, as in the so-called negro-heads (plate 1, fig. 7); or the lower end may be dark and the upper end pale coloured (plate 48, fig. 13); or again, one end of a crystal may be rose-red and the other end bright green, and so forth. Often also the zoning of the different colours is parallel to the faces of the prism; in fig. 7 the inner red portion is surrounded by a colourless layer and this again by an outer green layer. Tourmaline displays an endless variety in the zoning and distribution of its many colours.

The differences in the absorptive power of tourmaline for light is a very striking feature of the mineral. Some crystals when viewed through in a direction perpendicular to the prism planes are green or brown and transparent, but when viewed through the basal plane they are quite opaque even when only a thin plate is employed. Tourmaline being a doubly refracting substance, a ray of light on entering a crystal is resolved into two rays, the ordinary and the extraordinary (p. 58); and of these the ordinary, which vibrates perpendicularly to the principal axis, is almost wholly absorbed, only the extraordinary ray being allowed to pass through the crystal. The transmitted light is therefore plane-polarized, and on this peculiar property of tourmaline depends its use, when cut as a plate parallel to the prism, as a polarizer or analyser in the polariscope; such tourmaline plates, however, have the disadvantage of being deeply coloured,

and further the light is not completely polarized by them. Although all crystals of tourmaline do not exhibit such a marked difference in the absorption of the ordinary and extraordinary rays, yet this property of dichroism is always an important character of the mineral, and one readily recognized with the aid of the dichroscope. In the following table are stated the pairs of colours seen when a series of tourmaline crystals (all, except the last, being from Brazil) was examined with the dichroscope.

Colour of crystal.	Thickness of crystal.	Colour of ordinary ray.	Colour of extraordinary ray.
Colourless	1 cm.	colourless	colourless
Pale green, almost colourless	1 cm.	pale yellowish-green	pale water-blue
Green	2–3mm.	greenish-yellow to pistachio-green . .	water-blue to pale-green
Green	6 mm.	brown to black . .	green
Bluish-green . . .	3 mm.	bluish-green . . .	water-blue to colourless
Dark bluish-green . .	3 mm.	dark bluish-green, almost black . .	bluish-green
Blue	5 mm.	bluish-green . . .	pale blue
Pale rose-red . . .	5 mm.	rose-red	colourless
Pale rose-red . . .	1 cm.	violet-rose	rose-red with tinge of yellow
Deep violet-red . . .	7 mm.	reddish-violet . . .	delicate rose-red
Deep carmine-red . . (from the Urals)	8 mm.	reddish-violet . . .	yellow passing to rose-red

The strong dichroism of tourmaline must be taken into account by the lapidary, and a stone should be so cut from a crystal that the large table facet will be parallel to the prism: if it is perpendicular to the length of the prism the colour may be too deep, and in any case the light will be more strongly absorbed.

The refraction of tourmaline is not very high, but the double refraction is strong; the exact values of these vary somewhat with the colour of the stone and its chemical composition. Colourless tourmaline from the Island of Elba has a refractive index for the ordinary of 1·6397 and for the extraordinary ray 1·6208 as determined in sodium-light. The value of tourmaline as a gem-stone thus depends more on its bright colours than on any brilliancy of lustre.

The mineral possesses no cleavage. Its hardness is a little greater than that of quartz, being about $7\frac{1}{2}$, and the specific gravity varies from 3·0 to 3·2.

The chemical composition of tourmaline is one of extreme complexity, and although the mineral has repeatedly been analysed by mineralogical chemists it has not yet been possible to arrive at a general formula entirely free from objections. Difficulties are presented in the analytical operations owing to the presence, not only of so many constituents (fourteen appear in the following table), but of such elements as lithium, boron, titanium, and fluorine, which are not easily determined quantitatively. The following analyses may be quoted as examples: —

I, green tourmaline from Brazil, analysed by Jannasch.

II, brown tourmaline from Dobrawa in Carinthia (plate 48, fig. 3), analysed by Rammelsberg.

III, black tourmaline from Alabashka in the Urals, analysed by Jannasch.
IV, pale green tourmaline from Brazil, analysed by Riggs.
V, colourless tourmaline from De Kalb in New York, analysed by Penfield and Foote (1889).

	I Green	II Brown	III Black	IV Pale green	V Colourless
Silica (SiO_2)	37·05	38·09	35·41	37·39	36·72
Titanic oxide (TiO_2)	—	—	—	—	0·05
Boron trioxide (B_2O_3)	9·09	11·15	10·14	10·29	10·81
Alumina (Al_2O_3)	40·03	32·90	33·75	39·65	29·68
Ferric oxide (Fe_2O_3)	—	—	—	0·15	—
Ferrous oxide (FeO)	2·36	0·06	13·42	2·29	0·22
Manganous oxide (MnO)	2·35	—	—	1·47	—
Lime (CaO)	0·47	1·25	0·17	0·49	3·49
Magnesia (MgO)	0·32	11·79	1·57	—	14·92
Soda (Na_2O)	3·18	2·37	2·08	2·42	1·26
Potash (K_2O)	—	0·47	0·34	0·25	0·05
Lithia (Li_2O)	0·60	—	—	1·71	—
Water (H_2O)	3·23	2·05	3·41	3·63	2·98
Fluorine (F)	1·15	0·64	0·28	0·32	0·93
Total	99·83	100·77	100·57	100·06	101·11

In all of these analyses silicon, aluminium, and boron are largely present, and, in addition, II and V contain much magnesium, III much iron, and IV an appreciable amount of lithium. The tourmalines may therefore be classified chemically as magnesium-tourmaline, iron-tourmaline and lithium-tourmaline. Such a classification is, however, of little practical use, and here we shall, with the jeweller, group the tourmalines according to their colour and transparency.

Tourmaline is very resistant to acids, and only after fusion is it attacked by hydrofluoric acid. It is fusible before the blowpipe, the darker coloured varieties containing more iron being, as a rule, more easily fusible. In nature the mineral is usually found in a perfectly fresh condition, and only rarely is it altered to mica.

Tourmaline occurs embedded in granitic rocks and crystalline schists, either as isolated grains and thicker crystals or as radial aggregates of acicular crystals — the so-called tourmaline "suns". Sometimes its presence as a rock constituent is only to be recognized under the microscope; in text-fig. 193 radial aggregates of tourmaline needles embedded in quartz are shown in a thin section of granite. Embedded crystals on a larger scale are shown in plate 48, fig. 8, where the matrix is a lithia-mica. The occurrence of black tourmaline embedded in the quartz of granite is very common, and frequently the prisms have been broken across and cemented together again by quartz. Attached crystals are found, together with quartz, felspar, and other crystallized minerals, on the walls of cavities in granite (plate 48, figs. 1, 5, and 13; plate 1, fig. 7). Isolated crystals and water-worn fragments of tourmaline are also often found in river-gravels.

Black Tourmaline or *Schorl* is the most abundant variety and is rich in iron oxide. In thick pieces it is black and opaque, but in thin sections under the microscope

it is transparent with a dark brown or blue colour and strong dichroism. It sometimes forms very large crystals, which have usually been broken and cemented together again by quartz: smaller crystals are represented in plate 48, figs. 1, 5, and 11. More frequently it is met with as radial aggregates in granite. A few localities yielding the better crystals are: Hörlberg near Lam in the Bavarian Forest (fig. 5), Sonnenberg near Andreasberg in the Harz Mountains, Auerbach and Oberkainsbach in the Odenwald, the Island of Elba (fig. 1), Kragerö in Norway (fig. 11), Eibenstock in the Saxon Erzgebirge (here as large tourmaline "suns"), Alabashka near Mursinsk in the Urals, Pierrepont in St. Lawrence Co., New York (as very brilliant crystals bounded on all sides by faces), Monroe and Haddam in Connecticut, Greenland, Madagascar, etc. Black tourmaline finds no application as a precious stone.

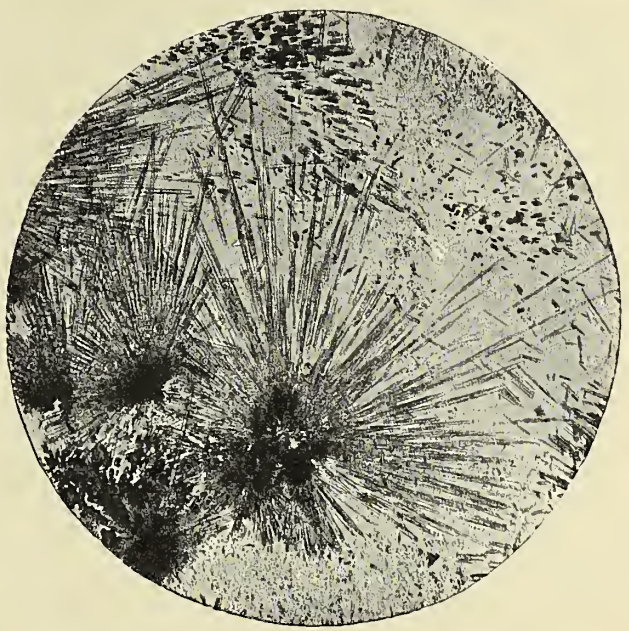

Fig. 193.
Tourmaline-granite from Luxullion, Cornwall. (Magnification 45).

Brown Tourmaline may be of a pale (fig. 12) or darker (fig. 3) shade, to almost black in colour. It contains much magnesia (analysis II) with only little iron, and is usually cloudy and fissured and with little transparency, although sometimes it is perfectly clear and transparent (fig. 14). It is found as embedded crystals in a white mica-schist at Dobrawa near Unterdrauburg in Carinthia (fig. 3), and in limestone at Gouverneur in St. Lawrence Co., New York (fig. 12). Material suitable for cutting is found in the gem-gravels in the district of Ratnapura in Ceylon, where tourmaline of other colours than brown is very rare. As a precious stone brown tourmaline is not very extensively used, and when cut into plates parallel to the prism it is sometimes employed in polarizing apparatus.

Red Tourmaline or *Rubellite* is widely distributed, but material of gem-quality is found at only a few localities. Good crystals of a pale rose-red colour are found in cavities of the granite at San Piero in Campo on the Island of Elba (fig. 2); these are often of a pale bluish or greenish colour at their lower end (fig. 15). Smaller crystals are found embedded in lithia-mica at Rožna in Moravia and Penig in Saxony. The best crystals are found in granite or in the weathered debris of this rock at Sarapulka and Shaitanka, respectively 12 and 48 kilometres from Mursinsk in the Ekaterinburg district of the Urals (fig. 6). These often closely approach the true ruby in their deep carmine-red or ruby-red colour; and they are consequently known as "Siberian ruby", they may, however, be readily distinguished by their lower specific gravity and strong dichroism.

Magnificant crystals of red tourmaline, often banded with green, are found at several places in the United States; thus, on Mount Mica near Paris in Maine, at Haddam in Connecticut, and more recently, at Mesa Grande in San Diego Co., California. In the neighbourhood of the last-named locality several mines are worked for tourmaline, and large amounts of material of gem-quality have within recent years been placed

on the market. The red tourmaline embedded in lithia-mica shown in fig. 8 is from Pala, also in San Diego Co., California. Red tourmaline also occurs in Brazil (fig. 7) and Madagascar, and two very fine specimens from Burma are exhibited in the Mineral Gallery of the British Museum.

Green Tourmaline of gem-quality comes principally from Minas Geraes in Brazil (figs. 4, 16, and 17), either as loose, sharply-developed crystals sometimes bounded by many faces, or as water-worn crystals. Some specimens approach the emerald in their green colour and are known as "Brazilian emerald": they may be distinguished from the true emerald by their higher specific gravity and stronger dichroism. Green tourmaline also occurs together with red tourmaline in the United States. A locality which has been long known for pale green tourmaline is Campo longo in the St. Gotthard district (fig. 10), where the crystals are embedded in a white crystalline dolomite.

Blue Tourmaline or *Indicolite* of a pure blue colour is of rare occurrence, though stones of a bluish-green and greenish-blue colour are more abundant. It is found together with the other coloured varieties in Brazil, and has been called "Brazilian sapphire". Crystals of a more greenish shade of blue are met with at Paris in Maine and Goshen in Massachusetts.

Application of Tourmaline. — Although formerly not much used in jewellery, tourmaline is at the present day greatly in favour, and large quantities of red, green, and bluish-green stones are now cut at Idar and Oberstein. The different coloured varieties as well as colourless tourmaline are classed under the term precious tourmaline, the fanciful and misleading names such as "Siberian ruby" and "Brazilian emerald" being fortunately little used by jewellers: no doubt the reason of this is that only recently has the value of tourmaline as a precious stone been fully recognized. Perfectly clear stones of a rich colour command high prices, but fissured and cloudy stones, which are extensively used as beads, are plentiful and correspondingly low in value.

Rose-red tourmaline may perhaps be confused with pink topaz, but it may be distinguished by its lower specific gravity and its different dichroism. The same characters also serve to distinguish tourmaline of different colours from emerald, ruby, sapphire, and spinel.

For polarizing apparatus tourmaline is now no longer made use of. Plates cut parallel to the prism from deeply coloured, brown or green crystals were formerly employed to a limited extent as polarizers and analysers (p. 59); and the so-called tourmaline tongs consist of two such plates mounted in a wire frame. When a suitable crystal section is placed between the two plates and viewed close to the eye this simple piece of apparatus shows the optical interference-figure of the section (plate 4).

Idocrase.

This mineral is frequently known as vesuvian or vesuvianite, since it occurs as specially fine crystals in the ejected limestone blocks of Monte Somma, the ancient portion of Vesuvius. Crystals are usually well developed and quite simple in form, and they afford the best examples of tetragonal crystallization. The accompanying text-figures and the majority of the crystals represented in plate 49 are bounded by the two square prisms M and d, the tetragonal pyramid c, and the basal plane P; and they differ amongst themselves mainly in the relative size of the basal plane. In figs. 4 and 17

the basal plane is absent; and in fig. 13 there are no pyramid planes. The crystals in figs. 5 and 11 differ only in the relative length of the prism faces. In fig. 8 the crystal is distorted by elongation in the direction of one of the horizontal axes. Some crystals of idocrase, especially those of small size, are very rich in faces, with several pyramids and eight-sided pyramids and prisms. Twinned crystals are unknown, but parallel grouping of crystals and zonal growths are not uncommon.

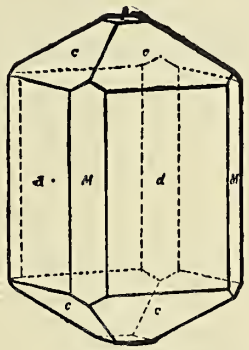

Fig. 194.

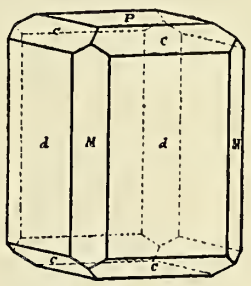

Fig. 195.

Crystals of Idocrase.

In addition to crystals, columnar aggregates, either straight a divergent, sometimes occur, as in the variety called egeran from Haslau near Eger in Bohemia.

The more usual colours are, as shown in plate 49, brownish-green and yellowish-brown; crystals of a pronounced yellow, reddish-brown (fig. 13), green (fig. 12), or black (fig. 14) are rarer. A bright blue colour is met with in the variety known as cyprine, which occurs as a granular aggregate, together with pink zoisite (thulite), in the parish of Souland, Telemark, Norway. Crystals of idocrase usually have only a slight degree of transparency; their lustre is vitreous. The refraction is fairly strong, but the birefringence very weak, the refractive indices for the ordinary ($\omega = 1{\cdot}7235$) and extraordinary ($\varepsilon = 1{\cdot}7226$) rays being only slightly different. The refractive indices vary slightly, however, in different crystals, probably owing to variations in the chemical composition. The same is true of the specific gravity, which varies from 3·35—3·45. The hardness is $6^1/_2$. The dichroism is not strong, and owing to the slight transparency of the crystals it is only rarely to be observed. Crystals from the Ala valley in Piedmont show in the dichroscope a greenish-yellow (*o*) and a grass-green (*e*) image.

Although so simple in crystalline form, in chemical composition idocrase is very complex. Analyses show the presence of water (1—2%), magnesia (3%), lime (36%), ferrous oxide (3%), alumina (16%), silica (37%), and often also fluorine (1%), boron, sodium, ferric oxide, and other consituents. No satisfactory chemical formula has yet been deduced. Idocrase is only slightly attacked by acids, and it is fusible before the blowpipe.

Idocrase is typically a mineral of contact-metamorphic origin, occurring, together with garnet and wollastonite, in limestones which have been altered to marble by contact with eruptive rock-masses. Crystals of idocrase embedded in crystalline limestone are represented in several figures in plate 49: in fig. 15 the matrix is a blue limestone The mineral also occurs in crevices in chlorite-schist (fig. 16) and in other rocks.

Some of the more important localities are: Monte Somma, Vesuvius (figs. 9, 14), the crystals being here embedded in blocks of crystalline limestone ejected by the ancient volcano. Mussa-Alp in the Ala valley, Piedmont (figs. 10, 11, 12), in serpentine. Canzocoli near Predazzo, Tyrol (figs. 4 and 5), in limestone at its contact with syenite. Also in contact limestones at Monzoni in southern Tyrol, Cziklowa and Dognacska in Hungary, and Auerbach in Hesse. Of Russian occurrences, the following may be mentioned: the district of the Wilui River in eastern Siberia (figs. 1 and 2), where idocrase and grossularite (plate 47, figs. 5 and 6) occur as fine crystals bounded on all sides by faces in a tuff-like rock (fig. 3); the Achmatovsk mines in the Zlatoust district of the Urals, as brown crystals on chlorite-schist (fig. 16) and as green crystals

in limestone (fig. 18). Other localities are: Egg near Christiansand in Norway (figs. 6 and 8), and very similar crystals are found at Sandford in Maine (fig. 7); Templeton in Ontario (fig. 13); Lewis and Clarke Co., Montana (fig. 15); and as large, corroded crystals at Magnet Cove in Arkansas (fig. 17).

Idocrase finds only a limited application as a precious stone, crystals from Vesuvius being occasionally cut at Naples, and those from the Ala valley at Turin.

Epidote.

This mineral is known sometimes as pistacite, on account of its characteristic colour resembling that of the pistachio-nut; this peculiar shade of green is shown in plate 50, fig. 1, and on the broken surface of the crystal in fig. 5, and it is also to be seen in the other crystals (with the exception of that in fig. 8) when they are held up against the light.

The crystals belong to the monoclinic system and are remarkable in being elongated in a direction perpendicular to the single plane of symmetry, that is, they

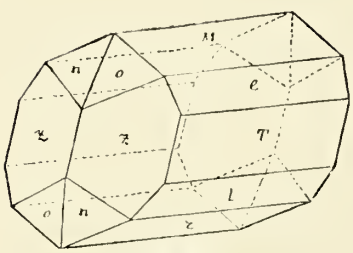

Fig. 196.
Twinned crystal of Epidote.

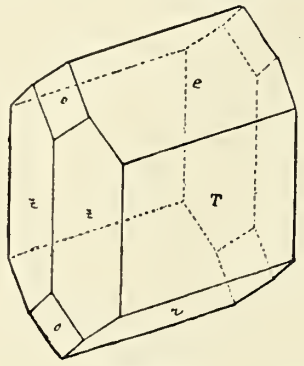

Fig. 197.

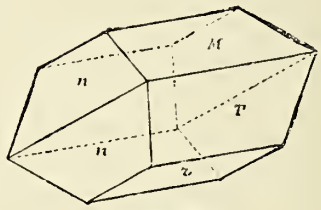

Fig. 198.
Crystals of Epidote.

are prismatic in habit in the direction of the ortho-axis b. This prismatic habit is especially pronounced in the long crystal shown in fig. 7, which is set up in the usual position adopted for monoclinic crystals with the plane of symmetry vertical; in fig. 3 the orientation is the same, only here the prism is much shorter. In the other figures on plate 50 the crystals are set up with the axis b vertical. As explained on p. 37 the choice of the clino-axis and vertical axis is arbitrary: in the (twinned) crystal in text-fig. 196 the ortho-axis b is parallel to the edge between M and e, the clino-axis a parallel to the edge between M and o, and the vertical axis c parallel to the edge between T and z. The face M then belongs to the basal pinacoid $0\,P$, T to the ortho-pinacoid $\infty P\bar{\infty}$, e is a face of the negative ortho-dome $-P\bar{\infty}$, and l and r of positive ortho-domes $2\,P\bar{\infty}$ and $P\bar{\infty}$ respectively; z the unit vertical prism ∞P, o the clino-dome $P\dot{\infty}$, and n the primary positive pyramid P.

Whilst in fig. 196 the crystal is prismatic in habit in the direction of the axis b, in fig. 197 it is tabular parallel to the ortho-pinacoid T, and in fig. 198, there is a tendency to a prismatic development along the edge of the pyramid n.

The crystals here represented are bounded by only few faces, but some crystals are very rich in faces, and for epidote more than 220 different forms have been recorded. These have, of course, not been all found on a single crystal, but on several crystals

from various localities, especially on the magnificant examples from the Knappenwand in the Untersulzbachthal, Salzburg.

Twinned crystals, with the ortho-pinacoid as the twin-plane, are of very frequent occurrence. These usually show re-entrant angles between the small faces at the ends of the crystals, as in text-fig. 196, and plate 50, figs. 5 and 8; but apparently simple crystals with an interlamination of fine twin-lamellae are frequent.

The crystals are sometimes broken and the portions displaced and again cemented together, as in the quartz crystal shown in plate 2a, fig. 7. Crystals with a zonal shelly structure are met with at Arendal, and from these successive envelopes of material can sometimes be readily removed.

In some of the transparent crystals with a pistachio-green colour, the strong pleochroism can be recognized with the unaided eye; viewed in one direction (perpendicular to the face *T*) they appear brown, and in another direction across the prism they are green. With the dichroscope the pleochroism may be seen in all directions, providing the crystals are sufficiently transparent. It is owing to the strong pleochroism that in certain crystals there may be seen with the unaided eye portions of a biaxial interference-figure, especially the hyperbolic brushes (as in plate 4, fig. 4, only more diffused) with coloured margins and rings. Such crystals are said to be idiocyclophanic, since they show rings of themselves, the double refraction and strong absorption of the crystal itself acting like a polarization apparatus. The refraction is fairly strong, the mean index being 1·7621 for green light.

The crystals possess a perfect cleavage parallel to the base (*M* in fig. 196), and a less distinct cleavage parallel to the ortho-pinacoid (*T*). The hardness is 6—7, and the specific gravity varies with the chemical composition from 3·3 to 3·5. The chemical constituents of epidote are silica, alumina, ferric oxide, lime, water, etc., but these are not present always in the same amount. The relative amounts of alumina and ferric oxide are especially subject to wide variation, and Professor G. Tschermak assumes that in epidote there is an isomorphous mixing of the molecules $H_2 Ca_4 Al_6 Si_6 O_{26}$ (a lime-alumina silicate, as in zoisite) and $H_2 Ca_4 Fe_6 Si_6 O_{26}$ (a lime-iron silicate). An analysis, by Ludwig, of epidote from the Knappenwand is given under I, and one, by Rammelsberg, of material from Arendal under II: —

	SiO_2	Al_2O_3	Fe_2O_3	FeO	CaO	MgO	H_2O	Total
I.	37·83	23·43	13·31	0·48	23·47	—	2·06	100·58
II.	38·76	20·36	16·35	—	23·71	0·44	2·00	101·62

Epidote is very resistant to acids, and only after fusion is it decomposed by hydrochloric acid. It is therefore but little affected by weathering processes: indeed many other minerals give rise to epidote by their alteration, as is shown by the occurrence of pseudomorphs of epidote after felspar, garnet, hornblende, and scapolite. This secondary epidote is usually granular, fibrous, or columnar, though sometimes it forms good crystals, and it may always be recognized by the characteristic pistachio-green colour. The larger crystals are found attached to the walls of crevices in crystalline rocks.

The finest crystals, far surpassing all others in size, brilliancy, and richness in faces, are from the Knappenwand in the uppermost portion of the Untersulzbachthal in Salzburg (plate 50, figs. 4—7): they occur in crevices in an epidote-schist, and are accompanied by colourless apatite, finely fibrous asbestos (shown in fig. 5), calcite, and a few other crystallized minerals This occurrence was discovered in the year 1866, and the yield has been extraordinarily rich, so that these fine crystals are to be seen

in every collection of minerals. Fine crystals of a brownish-yellow colour are found in the Ala valley in Piedmont, the large twinned crystal in fig. 8 a and b being from here. Other Alpine localities are: Zillerthal in the Tyrol, here as rose-red as well as green crystals; Zermatt in Wallis; Bourg d'Oisans in Isère, as bunches of columnar crystals terminated by drusy faces of the clino-pinacoid. Crystals very similar to the last are also found at Striegau in Silesia.

Large, cloudy, pistachio-green crystals are found in veins at Arendal in Norway (figs. 1 and 2). In these the form is much the same as in text-fig. 198, the upper face being the pyramid *n*, the large face to the front *M*, and the others *T* and *r*. Recently, large crystals of an unusual habit have been found in association with copper ore in metamorphosed limestone on Prince of Wales Island, Alaska. The larger crystals have the form of nearly square tables flattened parallel to the ortho-pinacoid, but in the smaller crystals this tabular habit is less pronounced and these sometimes assume the ordinary prismatic habit of epidote parallel to the axis of symmetry (fig. 3). These crystals are terminated by the clino-pinacoid, and when twinned these faces are marked by feather-like striations. With the epidote from this locality there are found, besides other minerals (magnetite, garnet), crossing twins of quartz similar to those from Japan. Fine crystals of epidote, often aggregated in druses, are found in the Achmatovsk mine near Zlatoust in the Urals, a mine noted for the fine mineral specimens which it has yielded.

An epidote in which the iron is largely replaced by manganese is found in the manganese mines of San Marcello in Piedmont, and, from the locality, it is called *piedmontite*. The crystals have the usual form of epidote, but they are cherry-red to reddish-black in colour, with little transparency, and a cherry-red streak. It mostly occurs as massive or fibrous aggregates in calcite.

The calcium aluminium silicate $H_2 Ca_4 Al_6 Si_6 O_{26}$, present together with the corresponding iron compound in epidote, also crystallizes alone in rhombic forms as the mineral *zoisite*. This usually forms columnar aggregates, without terminal faces, of a dull grey or yellowish colour; and it presents no specially characteristic features which enable this mineral to be readily recognized at sight. The specific gravity is 3·3, and the double refraction is weak. In one variety, known as thulite, it shows a bright rose-red colour; this occurs as granular masses, together with sky-blue idocrase (cyprine), in quartz in the parish of Souland, Telemark, Norway. Together with green hornblende (smaragdite) and brown garnet (plate 66, fig. 7), zoisite is a constituent of the prettily coloured rock eclogite occurring in the Fichtelgebirge in Bavaria and at the Sau Alp in Carinthia.

Application of Epidote. — This mineral is only rarely cut as a gem-stone. The transparent crystals from the Knappenwand supply suitable material for cutting, but these are much sought after by collectors, and the mineralogist prefers a fine crystal bounded by natural crystal-faces to a gem artificially cut. The colour is, moreover, not altogether pleasing and being very intense the stone has to be cut very flat, the most suitable form of cutting being the trap-cut.

Cyanite and Andalusite.

These two minerals, cyanite (plate 51, figs. 1—3) and andalusite (figs. 7—9), are identical in chemical composition, but different in crystalline form and all their physical characters. They are dimorphous forms of aluminium silicate, Al_2SiO_5, and contain, with the exception of fluorine, the same constituents as topaz.

Cyanite, or kyanite, as the name implies, is a mineral which is characteristically of a blue colour; this is usually a cornflower-blue (plate 51, figs. 1 and 2) or sky-blue, but sometimes bluish-green (fig. 3), whilst white, grey or almost black colours may also occur. The crystals are triclinic, and usually have the form of elongated columns or blades without terminal faces. In text-fig. 199 the large face *M* belongs to the macro-pinacoid, *T* to the brachy-pinacoid, the terminal face *P* to the basal pinacoid or base, and *o* and *l* are narrow prism planes. Twinned crystals, with the large face *M* as the twin-plane, are very frequent; the long crystal lying horizontally across the middle of fig. 1, plate 51, is a twin of this kind, and distinctly shows the re-entrant angle. Crystals of cyanite are sometimes intergrown with crystals of staurolite in a regular manner; this is shown in the long crystal in the lower part of fig. 1, the right-hand end being blue cyanite and the left-hand end brown staurolite. This remarkable regular intergrowth of two totally distinct minerals is further explained in text-fig. 199: the rhombic staurolite (the smaller crystal on the front) is attached to the triclinic cyanite with the faces *b* and *M* parallel and the edges of the prisms also parallel.

Fig. 199.
Regular growth of Staurolite on Cyanite.
(After Tschermak.)

In its physical characters, cyanite is remarkable in presenting considerable differences in hardness on different faces of its crystals and in different directions on the same face: on the face *M* in a direction parallel to the prism edge the hardness is 4—5, whilst on the same face in a direction at right angles the hardness is 6—7; and on the face *T* the hardness is about 7. These difference met with on one and the same crystal are as widely separated as the hardnesses of fluor-spar and quartz. The name disthene, employed by French writers, alludes to this difference in hardness. The crystals possess a very perfect cleavage parallel to the broad face *M*, and this is always shown by fractured pieces of the mineral (fig. 2). There is also a plane of separation parallel to the base *P*, which gives rise to cracks and striations on *M* nearly, but not quite, perpendicular to the prism edge. The specific gravity is 3·6. The pleochroism is very distinct in dark blue crystals, the two images seen in the dichroscope being dark blue and pale blue.

The mineral is not attached by acids. By weathering it passes into potash-mica, but as a rule it is little altered.

Cyanite occurs in crystalline schists, and the finest specimens are found with crystals of staurolite in a white mica-schist (soda-mica or paragonite) in the St. Gotthard district (fig. 1, plate 51), or embedded in the patches of quartz (fig. 2) in the same rock. A very similar occurrence is known at Litchfield in Connecticut. The occurrence in the gold-bearing sands of the Sanarka River in the southern Urals is of interest, since crystals resembling euclase in colour are found together with others of a deep blue. Cyanite also occurs as a constituent of the rock known as granulite.

Clear, deep blue cyanite is sometimes used as a gem-stone, but material suitable for this purpose is very rare. It is then known as sappharé, a name originally given in error instead of sapphire, but although the error has long been recognized the name is still used. Owing to its low degree of hardness in certain directions, cyanite is

little suited for use as a gem-stone, and since the colour is usually patchy and the stone only rarely clear, it is not much employed.

Andalusite. This mineral is identical with cyanite in chemical composition, but differs in its crystalline form. The crystals are rhombic, and are usually bounded only by a rhombic prism and the base, and since the angle between the prism faces is $90^0\ 48'$, the crystals are very nearly square in cross-section (plate 51, fig. 7). Generally the crystals are quite opaque and of a grey or reddish colour, and they are altered on their surface to potash-mica Clear and transparent andalusite is known practically only as pebbles from the gem-gravels of Brazil. The pleochroism of this material is so strong that the pebbles show an olive-green or a blood-red colour according to the direction the light is transmitted: in the dichroscope the two images are olive-green or oil-green and deep blood-red, similiar to those shown by the alexandrite of Ceylon. Although these two minerals are so similar in their pleochroism, they may be readily distinguished by their specific gravity and hardness: andalusite with a specific gravity of 3·1—3·2 floats in pure methylene iodide, while alexandrite (3·6) sinks; again, andalusite is much softer (H. = 7) than alexandrite. The refraction is not strong, the mean index being 1·638 for red light; and the lustre is therefore not much more than that of ordinary glass.

Crystals of andalusite when they occur embedded in clay-slate usually enclose much carbonaceous matter, which is collected along certain planes in such a manner that a cross-section of the crystal shows a black cross in marked contrast with the paler material of the rest of the crystal (plate 51, fig. 8 and 9). Owing to the resemblance of this cross to the Greek letter chi (χ), this variety of andalusite is known as chiastolite, or cross-stone. The black carbonaceous material is accumulated mainly in the centre of the crystal and along the edges of the prism, and in a cross-section there are darker rectangular patches, with their sides parallel to the prism faces, from which extend black lines to the centre. In fig. 8 these black patches at the corners are smaller and we have a black cross on a white ground, whilst in fig. 9 the black patches are much larger and little of the purer material remains, so that here we have a white cross on a black ground. In the latter figure the outer margins of the black areas are indefinite, there being here a gradual passage of the black material from the crystal into the surrounding rock. The carbonaceous material has no doubt been taken up and enclosed in the crystal during its growth, but exactly how this happened is not quite clear. Professor C. Hintze has suggested that a skeletal growth (similar to the skeletal growths in plate 2, fig. 3, of iron-pyrites and fig 10 of bismuth) rich in carbonaceous material was first formed by rapid crystallization, and that subsequently the interspaces became filled up by a slower growth of the pure andalusite substance.

Chiastolite is found only in clay-states which have been subjected to the metamorphic action of granite or some other igneous rock. The crystals are usually quite small and acicular, and they are found in vast numbers at Gefrees in the Fichtelgebirge, in Bavaria, in the slates around the Skiddaw granite in Cumberland, and at many other places. Thicker crystals (figs. 8 and 9) are found at Lancaster in Massachusetts. Large crystals of andalusite are found embedded in a vein of quartz in mica-schist at the Lisens Alp, Tyrol. Recently, considerable numbers of fine, large crystals of chiastolite have been found in clay-state at Mount Howden, ten miles north of Bimbowrie, in South Australia. The transparent pebbles already mentioned are found in the gem-gravels of the Rio dos Americanas in the Minas Novas district of Minas Geraes.

The transparent Brazilian andalusite is cut as a gem-stone, and chiastolite is cut in slices and polished; both are worked at Oberstein and the latter in large quantities. The striking black cross of chiastolite makes this stone especially suitable for amulets.

Staurolite.

Whilst chiastolite shows a cross in the interior, staurolite often has a cross-like form in the external shape of its crystals (plate 51, figs. 5 and 6), and the name staurolite again means cross-stone. This form is due to the twinning with interpenetration of two rhombic crystals. A simple crystal (fig. 4) is bounded by the faces of a rhombic prism, with a prism angle of $129^1/_2$, and the basal plane. The large simple crystal in fig. 1 shows, in addition to the forms in fig. 4, a face of the brachy-pinacoid (to the left) and a small face of the macro-dome $P\breve{\infty}$ over the obtuse prism edge (at the top to the left). When two individuals intercross at right angles, as in fig. 5 and text-fig. 200, they have in common a plane which would truncate the edge between the base and the brachy-pinacoid, this plane — a brachy-dome with the symbol $\frac{3}{2}P\breve{\infty}$ — being then the twin-plane. Obliquely intercrossing twins (fig. 6) have the pyramid $\frac{3}{2}P\frac{3}{2}$ as the twin-plane.

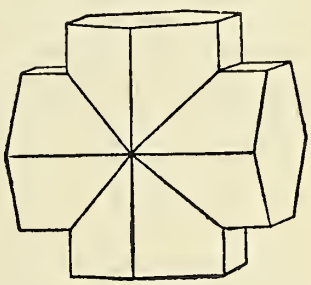

Fig. 200.
Twinned crystal of Staurolite.

The hardness of staurolite is about the same as that of quartz, and the specific gravity varies between 3·4 and 3·8. The colour is always brown. Staurolite sometimes occurs in regular intergrowth with cyanite (p. 255).

The chemical composition is very complex and variable, and a satisfactory formula has not yet been deduced. The mineral contains silica 30%, alumina 50%, ferrous oxide 12%, together with some magnesia, ferric oxide, and water. It is scarcely attacked by acids.

Staurolite principally occurs embedded in gneiss and mica-schist: and when these rocks are disintegrated by weathering the crystals are found loose in the surface soil, as in Brittany (figs. 4 and 5) and in Fannin County, Georgia (fig. 6). Brown crystals with a certain degree of transparency are found embedded with cyanite in white mica-schist in the St. Gotthard district (p. 255; plate 51, fig. 1).

Axinite.

This mineral receives its name on account of the characteristic axe-like form (ἀξίνη) of its sharp-edged crystals. All the faces and edges are inclined at oblique angles, and the crystals are therefore triclinic. The designation of the different faces is therefore quite arbitrary: in the text-fig. 201, we may take p to be the left vertical prism and u the right vertical prism, a the macro-pinacoid, s a macro-dome, and r and x as pyramid faces. We could, however, equally well take p as the macro-pinacoid, u the brachy-pinacoid, a the right vertical prism, r the base, s a brachy-dome, and x a pyramid. Indeed different crystallographers have adopted different orientations for the crystals in their endeavour to simplify the symbols for the faces.

The characteristic colour, as represented in plate 51, fig. 10, is clove-brown to brownish-violet, but it may also be pearl-grey or plum-blue. The lustre is brilliant and vitreous in character. Sometimes the crystals are dusted over with chlorite, and they are then dull and bluish-green with little transparency (figs. 11 and 12). The pleochroism is specially strong, the different shades of colour shown in fig. 10 being partly due to this. According to the direction a crystal is examined with the dichroscope the images are coloured cinnamon-brown and olive-green or violet-blue.

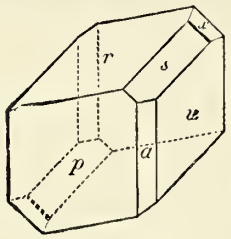

Fig. 201.
Crystal of Axinite.

The hardness is 6—7, and the specific gravity 3·3. The mineral is fusible before the blowpipe and imparts a pale greenish colour to the flame, proving the presence of boron. In this species also the chemical composition is very complex. An analysis of axinite from Bourg d'Oisans gave the following numbers, corresponding with the formula $H(Ca,Fe,Mn)_3Al_2BSi_4O_{16}$: —

SiO_2	B_2O_3	Al_2O_3	Fe_2O_3	FeO	MnO	CaO	MgO	H_2O	Total
41·5	4·6	17·9	3·9	4·0	3·8	21·7	0·7	2·2	100·3

Axinite occurs in crevices especially in diabase and hornblende-schist. The earliest known locality is Bourg d'Oisans in Isère (fig. 10). In the Swiss Alps the crystals are often coated with chlorite, as, for example, those from Piz Valatscha on Mt. Scopi (fig 11) and from Monte Prosa, St. Gotthard (fig. 12). Other well-known localities are Treseburg in the Harz, Thum in Saxony, Botallack Cliff near St. Just in Cornwall, Kongsberg in Norway, etc.

Clear crystals of axinite are sometimes cut as gem-stones, but only rarely are they met with in the trade. They may be distinguished from other brown stones by their peculiar shade of colour and their pleochroism.

Lapis-lazuli.

Lapis-lazuli, or azure-stone, is an almost opaque mineral distinguished by its intense blue colour, this colour being best shown by the very rarely-occurring crystals. A remarkable crystal is represented in plate 62, figs. 11*a* and *b*: this is a rhombic-dodecahedron with the octahedron and very small faces of the icositetrahedron 2 O 2. More frequently, the mineral occurs as irregular grains intermixed with other minerals, which may be present in smaller or greater amounts and predominate over the blue mineral. A typical specimen is represented in plate 62, fig. 12; here the blue material is lapis-lazuli and the white and brown is calcite, and in addition we see yellow, metallic specks of iron-pyrites; the latter is partly altered to limonite, this being the cause of the brown colour of some of the calcite. The best stones are of a deep blue colour with little intermixed impurities, and the somewhat inferior specimen figured in the plate is chosen rather to illustrate the typical character of the mineral. In some specimens the colour is pale blue, or passing into a reddish-violet, while in others it is greenish, but it is only those of a deep blue that are valued. When powdered, the pure mineral still shows the deep blue colour. And when the intermixed impurities are removed by washing, the dark blue powder which remains is the valuable pigment *ultramarine*. This purified material, like the crystal in fig. 11, represents a mineral species known as *lazurite*, the name lapis-lazuli being more correctly applied to the mixture of lazurite with other minerals (fig. 12).

In its chemical reactions this mineral is very remarkable, and in composition it is by no means simple. The fact that it effervesces in hydrochloric acid might be ascribed to the presence of admixed calcite, but the gas which is evolved consists of the evil-smelling sulphuretted hydrogen in addition to carbon dioxide. This cannot be from the iron-pyrites, which is not attacked by hydrochloric acid, and it must consequently result from the decomposition of the lazurite. At the same time the colour of the mineral is destroyed by the acid, and a jelly of silica separates; we must therefore conclude that lazurite is a silicate containing sulphur. The detailed investigations of W. C. Brögger and H. Bäckström have shown that the colouring material of lazurite is identical in composition with the artificial ultramarine, this being a silicate and sulphide of sodium and aluminium with the formula $Na_4(Na\,S_3.Al)\,Al_2(Si\,O_4)_3$. In the natural mineral, however, this is mixed with the isomorphous minerals haüyne and sodalite, and an analysis of material from Central Asia is explained by the intermixture of lazulite, sodalite, and haüyne in the molecular proportions of 15·7 : 7·4 : 76·9. The closely allied minerals haüyne (plate 62, fig. 10) and sodalite (fig. 8) are of importance as rock-forming minerals, and will be described in this connexion farther on, but lazurite being of importance in the precious stone lapis-lazuli is considered in this place.

The fact that lapis-lazuli always contains admixed calcite is readily explained by its mode of occurrence, it being a mineral of metamorphic origin in limestones altered by contact with igneous rock-masses. Water-vapour and sulphur compounds exuded by the igneous magma has penetrated the heated limestone, which may have contained some sodium and aluminium, and lazurite has been formed after much the same manner that ultramarine is manufactured.

The specific gravity of the impure lapis-lazuli is of course very variable, that of the purest naturally-occurring material being about 2·5: for the crystal represented in fig. 11 the value 2·516 was determined, and another smaller crystal gave 2.51. The hardness is about $5^1/_2$.

Lapis-lazuli is on the whole quite a rare mineral, and the material suitable from use as a precious stone comes from remote regions in Asia. The most important mines are situated in Badakshan, near the source of the Kokcha, a tributary of the Oxus in the north-east corner of Afghanistan. The stones obtained here are conveyed by way of Bukhara into Russia, or they find their way into the market through China and Persia. As with other precious stones (e. g. the Syriam garnet, p. 242), the places through which they have passed before coming into the market are sometimes stated to be the localities at which they are found. In this way lapis-lazuli is sometimes erroneously said to come from Bukhara, China, and Persia. Another Asiatic locality where the stone is mined is in the neighbourhood of Lake Baikal. The richest deposits are on the Bistraya river, where nodules of lapis-lazuli weighing as much as 50 kilograms have been found. The material from here is blue, but also violet and green, and it contains less iron-pyrites than that from Badakshan. Lapis-lazuli is also known from the Chilian Andes, and as a rarity from Vesuvius and the Albanian Hills near Rome.

Application. — Lapis-lazuli is usually cut with a flat surface and worn as a ring- or pin-stone, or it is cut as small beads and worn on chains. It is also used, like agate, for some larger objects, such as knife-handles, seals, paper-weights, etc. On a still larger scale it is sometimes used for inlaying and mosaics, as on the walls and ceilings of the palaces of princes, and the columns of churches.

Even in remote times lapis-lazuli was worn as an ornamental stone, it having been found in the ruins of ancient Troy (p. 203). Only rarely was it used as a material

for engraving, the lack of homogeneity rendering it unsuitable for this purpose. At different periods the stone has been known by different names: to the Greeks it was known as kyanos, a name now applied to the blue mineral cyanite (p. 255). Later, it was called sapphire, as may be gathered from a passage in Pliny: "in the blue sapphire sparkle specks of gold, like the blue sky bedecked with stars" — the "specks of gold" being, of course, the grains of iron-pyrites scattered through the stone. The name lapis-lazuli was first used in the middle ages.

Agate which has been artificially coloured blue is sometimes sold as lapis-lazuli, and especially at watering-places to the unwary. The deception can, however, be recognized at a glance, agate being translucent and more compact in structure, and further considerably harder.

Formerly, the pigment ultramarine was obtained from lapis-lazuli, and was then very expensive, but now it is prepared synthetically.

Turquoise.

Like lapis-lazuli, turquoise or calaite, is an opaque precious stone valued for its fine colour. The colour is a pure sky-blue (plate 82, figs. 10—12), or it may be bluish-green or green. The mineral is compact and exhibits no crystalline form, but sometimes, when forming an encrustation, it presents a botryoidal surface. Usually, however, it forms veins, filling the cracks and crevices in rocks, and in this respect resembling opal in mode of occurrence. It exhibits a soft, waxy lustre, and in thicker pieces is opaque. Thin flakes when examined under the microscope are transparent, and under a high power the material is seen to consist of an aggregate of minute grains and scales.

The colour of turquoise loses none of its beauty by lamplight. On exposure to a strong light, such as direct sunlight, for a long time the colour of some specimens fades, and in all cases it is destroyed by fire. When heated before the blowpipe, the mineral becomes black and, without fusing, falls to powder; this affords a method of distinguishing between true turquoise and the very similar imitations, which are fusible before the blowpipe. A splinter of turquoise held in the non-luminous flame of the Bunsen-burner imparts a green colour to the flame, since the mineral contains phosphoric acid and copper. In its chemical composition, turquoise is of interest in being the only precious stone containing phosphoric acid; it is essentially a hydrated phosphate of aluminium, containing small amounts of copper (2—7% copper oxide) and iron probably in combination as phosphates. An analysis of turquoise from Persia gave: phosphoric acid 29·4%, alumina 42·2%, ferrous oxide 4·5%, copper oxide 5·1%, and water 18·6%. The chemical formula is $[Al(OH)_2]_3PO_4$, the group $Al(OH)_2$ being partly replaced by $Fe(OH)_2$ and $Cu(OH)$ or by hydrogen. The hardness of the mineral is 6, and its specific gravity 2·6—2·8.

The most important locality is in Persia, between Nishapur and Meshed, where the turquoise occurs in a weathered porphyritic rock and has been mined since very early times. Besides being found in situ, it is also found as pebbles in the debris of the river courses. Turquoise mines are also worked in the Meghâra valley in the Sinai Peninsula (plate 82, fig. 10). Here the mineral occurs in the Nubian sandstone, and on Mount Serbâl in porphyry. These mines were worked by the ancient Egyptians 4000 B. C., and at the present time by the Egyptian Development Syndicate. Turquoise

of excellent quality is also found at several localities in the western states of the United States: thus, in the Columbus district of Nevada (plate 82, fig. 11); Cochise Co., and Mineral Park in Mohave Co., Arizona; and several places in New Mexico (fig. 12), especially in the neighbourhood of Santa Fé. Green turquoise, of no value as a precious stone, occurs as veins in quartz-schist at Jordansmühl in Silesia.

From early times turquoise has been worn by both civilized and savage races as an ornamental stone, being admired an account of its bright sky-blue colour. The stone is cut and polished with a convex surface, like the opal. Large stones are often set with a border of small brilliants, or are worn as pin-stones: smaller stones are mounted close together to give more effect to the colour. As a material for engraved gems it was used especially in the Augustan period, but curiously green turquoise was mainly employed for this purpose, and glass imitations were also made. At the present day much of the material sold as turquoise is nothing more than a glass imitation; this may be recognized by a careful inspection of the lustre, which is vitreous in glass and waxy in turquoise; further, if a fragment is broken off this will be more transparent and glassy in the imitation stone. Much better imitations of turquoise have been made by submitting to a great pressure a chemical precipitate having the same composition and colour as the natural stone: this is difficult to detect, but before the blowpipe it is fusible, whilst genuine turquoise falls to a black powder.

The so-called *bone-turquoise* or *odontolite* is also sometimes passed off as real turquoise. This consists of the fossil bones and especially teeth and tusks of extinct animals (Mastodon) which have been coloured blue by phosphate of iron. It is found mainly at Simone in France. In lamplight this material appears of a dull grey colour; and it may further be distinguished from true turquoise by the fact that it effervesces with acid (owing to the calcium carbonate present in bone), and when heated it gives a smell of burning organic matter.

The value of turquoise depends on the purity of the sky-blue colour and on the size of the stones; material of a greenish-blue or green colour is now held of little value. A good quality stone weighing one carat costs about fifty shillings, but stones of larger size are worth much more than this per carat.

Variscite. In external appearance this mineral (plate 82, fig. 13) is very similar to green turquoise. It also is compact in texture, and in composition a hydrated phosphate of aluminium, the formula being $Al PO_4.2H_2O$, corresponding to phosphoric acid 44·9%, alumina 32·3%, and water 22·8%. The fine emerald-green or verdigris-green colour is due to the presence of small amounts of iron oxide and chromic oxide. This mineral occurs, like turquoise, as veins in the crevices of rocks. It is found in quartz-schist or quartz at Messbach near Plauen in Saxony, in Montgomery County in Arkansas, and in Utah (plate 82, fig. 13).

Minerals of the Quartz Group.

Of all minerals, quartz is the most abundant and widely distributed. It is an essential constituent of rocks of many kinds, and it thus forms a large part of the earth's crust. With the weathering of these rocks, the resistant and insoluble quartz remains in the soil, and there are few soils and surface accumulations in which quartz is not largely present. It forms part of the rocks of the highest mountain peaks, and as loose grains it forms the sand of the sea-shore.

Crystals of quartz, clear as water and ice, are found in the Alps in the region of perpetual snow, and it was quite natural that the ancients believed them to be ice which had been so intensely frozen that it could not be again melted. The Greek word κρύσταλλος (krystallos), meaning clear ice, therefore came to be applied to these crystals of quartz, and even to the present day they are known as rock-crystal.

Quartz, with its marked differences in colour, transparency, and structure, is represented by an very large number of varieties, to which special names were applied long before it was known that they belonged to the same mineral-species: and owing to the importance of many of these varieties as precious stones these names are still in use. Rock-crystal is a colourless, transparent variety, amethyst is violet quartz, smoky-quartz is brown and transparent, and other names are applied to the yellow varieties; while cloudy material with little transparency is called common quartz.

The material of which quartz is composed is silica or silicon dioxide, SiO_2 But besides forming prismatic and pyramidal crystals of quartz, silica also forms thin tabular crystals of a much rarer mineral known as tridymite. The same material also forms finely fibrous masses with a botryoidal, reniform, or stalactitic exterior; being then known as chalcedony. Finally, when combined with a variable amount of water it forms amorphous masses of opal. Quartz, chalcedony, and opal are all of importance in that they supply a large number of precious and semi-precious stones; while tridymite is of interest as representing a different crystalline modification of silica.

Quartz and its Varieties.

Between the form of quartz crystals and their colour and transparency there is in some degree a certain connexion. The simplest forms are met with in the cloudy common quartz, crystals with a larger number of faces are usually of the rock-crystal and smoky-quartz varieties, while complexity of internal structure is more often associated with amethyst.

The simplest form is the double hexagonal pyramid (plate 52, figs. 1, 5, and 6), with an angle of 133° 44′ between two adjacent faces which meet in a sloping edge. The horizontal edges of this double pyramid are almost always truncated by the faces of a hexagonal prism, which may be smaller (figs. 7, 8, and 4) or larger (figs. 3 and 9) in size. These prismatic faces are almost invariably marked by striations perpendicularly to the edges of the prism (plate 54, fig. 1); when the crystal is set up vertically, as in the figures, these striations will be horizontal, and they are very often helpful in correctly orientating a distorted crystal. The faces of the pyramid are frequently of different sizes (plate 54, fig. 1); at each end of the crystal three of the faces being larger and brighter than the three alternate faces. The apparent hexagonal pyramid of quartz is therefore a combination of two rhombohedra, the positive rhombohedron $+R$ and the negative rhombohedron $-R$; the symbol of the hexagonal prism then being ∞R. The angle between the faces of each of these rhombohedra is 94° 15′.

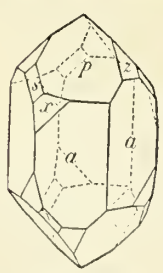

Fig. 202.
Left-handed crystal of Quartz.

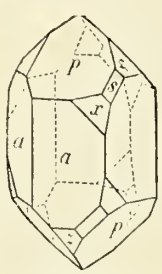

Fig. 203.
Right-handed crystal of Quartz.

In addition to these commonly-occurring faces these are sometimes present smaller rhomb-shaped faces lying above the vertical edges of the prism (plate 54, figs. 5 and 6). These so-called rhomb faces have the position of a pyramid of the second order, but

in a perfect crystal they are developed at the two ends of alternate prism edges (*s* in text-figs. 202 and 203): if developed as a simple form they would give a double triangular pyramid. The edges between these rhomb faces and *one* of the adjacent prism faces are sometimes truncated by faces of another form (plate 54, figs. 2 and 3; *x* in text-figs. 202 and 203); these are known as trapezohedral faces, and they are placed obliquely above and below alternate edges of the prism. Their position is that of the faces of a twelve-sided double pyramid, but instead of twenty-four faces only six are developed. In quartz, therefore, only one quarter of the full number of faces possible in the general form of the hexagonal system are developed; the crystals are consequently described as tetartohedral, and they belong to the trapezohedral-tetartohedral class of the hexagonal system. The Naumannian symbols for these faces are somewhat complex; for the rhomb faces $s = \frac{2\,P\,2}{4}$, and for the trapezohedral faces $x = \frac{6\,P\,\frac{6}{5}}{4}$. The symbols for the other faces in text-figs. 202 and 203 are $a = \infty$ R, $p = +R$, and $z = -R$. Numerous other faces have been recorded on quartz crystals but they are rare, and the basal plane is extremely rare as a small corroded face. Narrow faces of steeper rhombohedra are seen in plate 54, fig. 3.

Except in very rare cases, the trapezohedral faces are placed beneath the positive rhombohedron (*p*), and lie either to the right or to the left of a prism face. Right-handed (text-fig. 203; plate 54, fig. 2), and left-handed (text-fig. 202, plate 54, fig. 3) crystals of quartz are therefore to be distinguished. These are related to one another like the right and left hands; one is the mirror-reflection of the other, and they cannot be brought into superposable positions. Such crystals are said to be enantiomorphous, and there is a close connexion between their external form and their optical properties: right-handed crystals rotate the plane of polarization of plane-polarized light to the right, and left-handed crystal rotate it to the left.

Fig. 204.
Rock-crystal showing layers of growth ("Ghost-quartz"): from Goyaz, Brazil.

Irregularities and distortion of the form is very frequent in crystals of quartz, due, as already explained (p. 42, and plate 2a), to the unequal extension of the faces. Twisted crystals, due to the aggregation of particles in not quite parallel positions, have also been mentioned in the same place. Some crystals of quartz exhibit a pronounced shelly or zonal structure, being built up of a number of concentric shells of material, and indicating that the conditions under which the crystals grew must have varied from time to time. In plate 52, fig. 11, this structure is marked out by the alternation of lighter and darker bands. In the

transparent rock-crystal shown in text-fig. 204, the stages of growth of the crystal are marked out by thin, snow-white layers parallel to the external faces, and we see one crystal within another; such a specimen is known as ghost-quartz. Here the thin, snow-white layers are due to the enclosure in the quartz of vast numbers of minute air spaces. In other cases the stages of growth are rendered evident by bands of chlorite or other foreign material, which was thinly deposited on the surface of the crystal before its growth was completed: the crystal can then often be readily broken up into the several shells of material, as in the so-called capped quartz (plate 52, figs. 12 a and b). An internal lamellar structure of another kind is detected when crystals are carefully examined in polarized light: this consists in the repeated interlamination of thin layers of right-handed quartz and of left-handed quartz, a pecularity in structure especially characteristic of amethyst.

Twinning is of frequent occurrence in quartz, but the twinned crystals have, at first sight, quite the appearance of simple crystals, the twinning being rendered evident only in the distribution or surface characters of the faces; only rarely do they show re-entrant angles, enabling them to be recognized at a glance as twins. The several types of twinning of quartz are illustrated in plate 53.

In the crystal represented in fig. 1 the only evidence of twinning is seen in the irregular distribution of bright and dull areas on the rhombohedron faces (best seen on the rhombohedron face to the front in the figure): the brighter areas belong to the positive rhombohedron (+ R), and the dull areas to the negative rhombohedron (— R). To explain this coincidence of the faces of the two rhombohedra, consider two crystals placed side by side in parallel position, as in text-figs. 202 and 203, and with a face of the positive rhombohedron (p) directed to the front: if now we rotate one of the crystals through 180° about the vertical axis, a smaller face z of the negative rhombohedron will come to the front and be parallel to p of the other crystal. The two crystals will then be in twinned position with respect to one another, and if they were grown together with interpenetration the faces p and z would be coincident. This type of twinning is rendered still more evident if the crystals carry trapezohedral faces, since in the twinned crystals these faces will be present above *all* of the prism edges: in fig. 2 we have such a twin intergrowth of two right-handed crystals, and in fig. 3 of two left-handed crystals, while in fig. 4 the intergrowth is of a left-handed crystal with a right-handed. Twins of the kind shown in figs. 2 and 3 are common, but distinctly developed twins like fig. 4 are extremely rare and are to be seen in very few collections (the one figured being in the collection of Mr. Gustav Seligmann, of Coblenz). The last of these, being met with in amethyst from Brazil, is known as the Brazil twin; and although it is rarely shown by the distribution of the trapezohedral faces, it is in fact extremely common, as proved by the optical examination of crystals.

In the twins so far considered the two individuals are intergrown with their axes parallel. In figs. 5 and 6 the twinning is much more conspicuous, the principal axes of the two individuals been almost at right angles (actually 84° 33′). Here the twin-plane is a face of a pyramid of the second order $P\,2$. Twinned crystals of this type have long been known from Bourg d'Oisans in Isère (fig. 5), and more recently large numbers have come from Japan (fig. 6, and plate 54, fig. 12). Smaller examples are known from Munzig in Saxony, occurring here with mispickel, and with epidote from Alaska.

The *physical characters* of quartz also present several points of interest, and of special importance is that circular polarization (p. 61). A plate cut from a clear crystal perpendicularly to the edges of the prism, when examined in the polariscope between crossed nicols is not dark, as with other optically uniaxial crystals, but is uniformly

coloured. Further, as the upper nicol (the analyser) is rotated, the colours change, and from the order in which these appear we can determine whether the rotation of the plane of polarization is to the right or to the left. If, for example, the plate shows a red colour, the analyser must be rotated to the right (clock-wise) with a plate of right-handed quartz, or to the left (counter-clock-wise) with a plate of left-handed quartz, for the colours to appear in the order of succession shown in the spectrum of white light—namely, red, yellow, green, blue. If the analyser be rotated to the right with a plate of left-handed quartz, this order of the colours will be reversed. A plate cut from a twinned crystal consisting of an intergrowth of right-handed and left-handed quartz will, in different portions, show the two orders in the succession of colours. In such a plate, where there is an overlapping of right-handed and left-handed quartz, the rotary polarization will be neutralized, and between crossed nicols there will be darkness: this is well shown in text-fig. 205 along the black lines in the middle of each of the clear sectors. The clear portion on one side of each of these lines is right-handed quartz and that on the other side left-handed quartz. The finely banded portions in the same figure consist of a more intimate interlamination of right-handed and left-handed material.

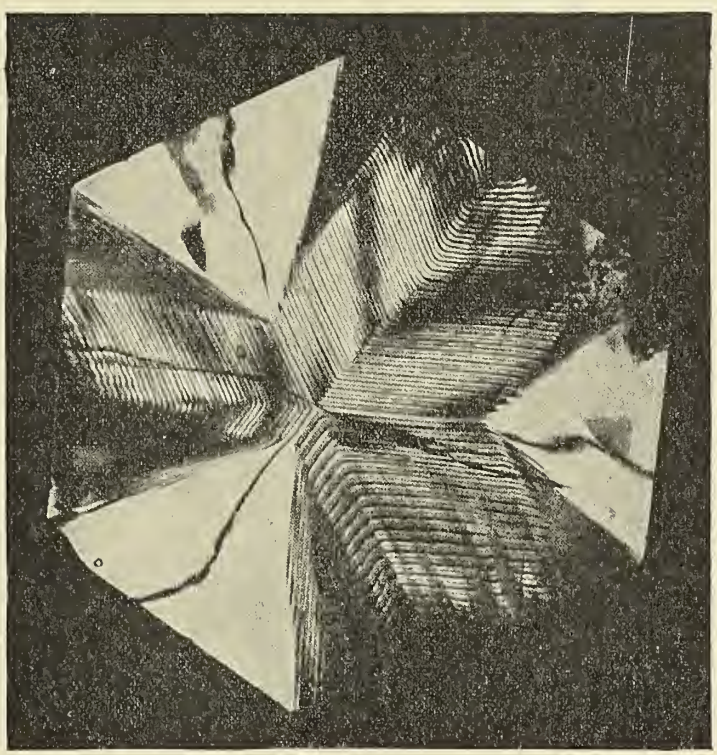

Fig. 205.
Plate of Amethyst cut perpendicularly to the principal axis; in parallel polarized light.

In convergent polarized light plates of quartz show a uniaxial interference-figure of a peculiar kind: the black cross does not extend towards the centre beyond the innermost ring, the centre of the figure being clear, or, in white light, coloured (plate 4, fig. 2). A still further modified interference-figure is shown by a plate cut from a twinned crystal consisting of right-handed and left-handed material: where there is over-lapping of the two portions a complex system of coloured spirals (Airy's spirals) is seen.

The *refraction* and dispersion of quartz are both low, and consequently a cut stone displays neither a brilliant lustre nor a strong fire; the double refraction is also low. The refractive indices in sodium-light are 1·54415 for the ordinary ray and 1·55329 for the extraordinary ray.

The *colouring* of quartz is sometimes due to the presence of mechanically admixed pigments: for example, the red colour of the crystals in plate 52, figs. 8 and 9, is due to iron (ferric) oxide, the yellow colour of the crystals in fig. 10 to hydrated oxide of iron, and the black of figs. 6 and 7 to carbonaceous matter. In the transparent, coloured varieties of quartz, however, the colouring matter is not present in this form,

but is actually dissolved in the quartz substance, like a salt is dissolved in water. This is present only in minute traces, and different investigators are not agreed as to whether it is organic or inorganic, both hydrocarbons and titanium compounds having been suggested as the cause of the colour.

The hardness of quartz is 7 on the scale, and its specific gravity is 2·65. The mineral breaks with a conchoidal or splintery fracture; and sometimes a very imperfect cleavage parallel to the faces of one rhombohedron is observable.

The *melting point* of quartz is about 1700° C., and the fused material consolidates as a clear glass; this melts at a slightly higher temperature and can be worked like ordinary glass. In recent years extensive use has been made of fused quartz for chemical apparatus, such as crucibles, etc. The softening temperature of this silica glass is about 800° C. higher than that of ordinary glass, and it further has the very great advantage that it is not affected by sudden changes of temperature: a crucible of silica glass may be raised to a red-heat and immersed into cold water without being broken or cracked. The specific gravity of this fused quartz is only 2·2, and its refractive index 1·45.

Quartz is very resistant to chemical reagents, and is completely dissolved only by hydrofluoric acid. That quartz is sometimes acted upon by natural solutions is shown by the occurrence of corroded crystals with etched figures on the faces (p. 21, plate 55, fig. 3). From the orientation of the etched figures it is sometimes possible to distinguish between right-handed and left-handed crystals of quartz.

Enclosures of other minerals are very frequently seen in crystals of quartz. In plate 54, fig. 9, we see needles of green actinolite, somewhat resembling blades of grass, enclosed in a colourless crystal: and in fig. 8 a network of brown needles of rutile, like the rutile in plate 19, fig. 10. Bundles of long rutile needles are enclosed in the crystal shown in plate 55, fig. 4. Rock-crystal with these enclosures of rutile is known as hair-stone, magnificant specimens of which have recently been obtained from Goyaz in Brazil. The black enclosures in plate 54, fig. 7, consists of asphalt. In the thin rock-section shown in plate 59, fig. 3, we see enclosures of glass in the quartz of a porphyry; this rock was formerly in a molten condition, and the growing quartz crystals caught up drops of the molten material before it had consolidated to a glass. The quartz of granite is frequently rich in enclosures of liquid carbon dioxide and of saturated solutions of sodium chloride. The enclosure of native gold in quartz has already been mentioned (p. 75). Quartz sometimes form regular intergrowths with felspar (as in graphic granite), and more rarely with calcite.

Although formed so abundantly in nature, the *artificial production* is quartz is not readily achieved. Small crystals have been prepared by the action of superheated water vapour on glass and gelatinous silica, and also deposited from solutions containing fluorine. The conditions under which enormous crystals of clear quartz have been formed in nature are not known.

Quartz is the most stable of minerals and it frequently takes the place of other minerals when these are altered, pseudomorphs of quartz being of common occurrence. Occasionally, however, other minerals may replace quartz, as in the rare pseudomorphs of steatite after quartz (plate 69, fig. 11).

We now pass to a more detailed description of the several *varities* of quartz.

Rock-crystal is the transparent, water-clear variety of crystallized quartz. The crystals are brilliant and often carry the rarer faces *s* and *x* of text-figs. 202 and 203. In size they vary very considerably: the largest crystals are over a metre in length and circumference and weigh several hundredweights, whilst others are so small that

they can only be seen under the microscope. Distorted crystals are common in rock-crystal, while twisted crystals are more usual in smoky-quartz. Rock-crystal is represented in plate 1, fig. 9; plate 2, fig. 8; plate 2a, figs. 1, 4, and 7; plate 54, figs. 1, 4, 5—9, and 11; and as twinned crystals in plate 53, figs. 1, 3, 5, and 6.

Rock-crystal is widely distributed in crevices and larger cavities, the so-called crystal caves, in the granitic rocks of the Alps, and is often accompanied by adularia, sphene, rutile, chlorite, and other crystallized minerals. The crevices and cavities are usually closed, and it requires a practised eye and considerable experience to detect their presence. A small quartz-vein visible on the side of a precipice may lead to a crystal cave. A person who makes his livelihood by searching for and collecting rock-crystal is known in Switzerland as a "Strahler". The occupation is a dangerous one, and the yield but small, it being only rarely that large crystals are found in numbers. Perfectly water-clear crystals of quartz, sometimes twinned according to the Brazil-law, are found in cavities in the snow-white marble of Carrara in Tuscany (plate 54, fig. 11). Large, clear crystals are known from the State of Goyaz in Brazil (plate 55, figs. 3 and 4, and text-fig. 204), and fragments of gigantic crystals come from Madagascar. Good crystals also come from India; and these are often terminated by only one rhombohedron. Water-clear crystals, bounded on all sides by faces and sometimes enclosing asphalt, are found in Herkimer Co., New York (plate 54, fig. 7); and smaller crystals in the Marmáros Comitat in Hungary, and in the Hessian County of Schaumburg. Minute water-clear crystals are often found embedded in gypsum and carnallite. Rock-crystal with hopper-shaped depressions on the rhombohedral faces are found at Poretta in Italy (plate 2, fig. 8).

Application. — Ever since the Mycenaean epoch rock-crystal has been employed as a precious stone, for engraved gems, and for the carving of various costly ornaments. It is probable that the ancients had observed the magnification of objects when viewed through clear crystal cut with rounded surfaces; and it is therefore not unlikely that the gem engravers made use of lenses of rock-crystal in their minute work. The Roman physicians are said to have used spheres of rock-crystal as burning glasses for burning out wounds. At the time of the Roman emperors and during the Renaissance beautiful vases and bowls were artistically carved in rock-crystal. The so-called crystal used for similar vessels at the present day is only cut glass, rock-crystal being scarcely ever now employed for this purpose.

At the present day rock-crystal, which is mainly of Brazilian origin, is cut as spectacle lenses, weights for delicate balances, seals, paper-weights, crystal balls, etc. It is also extensively cut in the brilliant form for jewellery; such stones have quite a good effect by themselves, but in comparison with the diamond they appear dull, showing neither brilliancy of lustre nor play of prismatic colours. Rock-crystal with enclosures of needles of rutile or of green actinolite is cut with a low rounded surface, in order to show these enclosures to the full advantage: such material may be employed for letter-weights, seals, or balls. Pure rock-crystal is also used for the manufacture in fused silica of crucibles and other apparatus (p. 266).

Smoky-quartz (or "smoky-topaz") is a brown, transparent quartz. The colour varies from pale brown to dark brown, and when almost black the material is known as *morion* (plate 54, fig. 10). The colouring matter is probably a hydrocarbon or some other organic substance, since it is readily affected by heat, the colour of the crystals being destroyed at a temperature as low as 360° C. It must therefore be concluded that crystals of smoky-quartz were formed at a temperature less than 360° C. Enclosures of other minerals are much less frequent in smoky-quartz than in rock-crystal. The

dichroism is strong; as seen in the dichroscope, the extraordinary image is brownish-yellow and the ordinary image pale brownish-violet or pale brown to almost colourless. The same crystal-faces are present on smoky-quartz as on rock-crystal, and we find the same distortion of the crystals, though twisted crystals are more frequent in smoky-quartz (plate 2, fig. 12; plate 2a, figs. 2 and 3) than in rock-crystal. A fine group of crystals of smoky-quartz is represented in the frontispiece; the crystals are doubly-terminated, and both right-handed and left-handed crystals are to be seen; the smaller white crystals are albite.

Smoky-quartz occurs in the Alps under the same conditions as rock-crystal. A remarkable crystal cave was discovered in 1868 on the Tiefen glacier near the Furka Pass: 300 hundredweights of crystals were found, the largest being 69 centimetres in height and weighing 133 kilograms. The best and largest of these crystals are now in the museum at Berne. The St. Gotthard district is especially rich in large, clear crystals of smoky-quartz; the specimen represented in the frontispiece, and those in plate 54, figs. 2 and 3, being from this district. In other regions smoky-quartz is, on the whole, rarer than rock-crystal. Clear material of good quality is found in Goyaz, Brazil.

Smoky-quartz has at various times been much used as a gem-stone, though now it is not much in favour. It is fashioned into seals, balls, and other small ornaments.

Yellow and brownish-yellow, transparent Quartz. Besides smoky-quartz, there are other colour-varieties of quartz which are of importance in the trade, being known to jewellers as "topaz" with some qualifying prefix.

Yellow quartz is citron- or orange-yellow in colour. The material as it comes into the market has usually the form of long, broken prisms rarely with terminal faces, while the prism-faces are often marked with etching figures. The fractured surfaces are conchoidal and smooth without ripple markings. The dichroism is strong, the colours being pale yellow for the ordinary ray and dark yellow for the extra-ordinary. In polarized light the material behaves like rock-crystal, though it is only rarely that there is an intergrowth of right-handed and left-handed quartz. Material of this description comes from Brazil, and it is only rarely met with in the trade.

"*Golden topaz*" differs from the preceding only very slightly in colour, but this is always of a pale shade. It comes into the market mostly as broken fragments, and only exceptionally are terminal faces present (plate 56, fig. 9). The fractured surfaces exhibit the peculiar ripple-like markings (so-called thumb-markings) so characteristic of amethyst, and in this respect "golden topas" differs from yellow quartz. In polarized light the material behaves like amethyst (compare text-fig. 205, p. 265), and, indeed, according to the statements of the traders it is a burnt amethyst. In any case, the material is imported as "golden topaz", and it is said to have been burnt in Brazil. When heated, amethyst changes to yellow in colour, but the material is usually thereby fractured, unless the heat be applied very gradually and uniformly, this being effected by embedded the crystals in sand.

As broken fragments, "golden topaz" is exported from Brazil in large quantities, and at the auction sales at Idar in Germany it fetches from 20 to 60 marks (£1 to £3) per pound according to the clearness and size of the pieces.

Citrine is a name applied by mineralogists to transparent quartz of a citron-yellow or wine-yellow colour, and it includes the two foregoing varieties; but in the trade this name is little used. The island of Arran is given as a locality; and a cut stone is represented in plate 54, fig. 13.

"*Brown topaz*" also known as "Brazilian topaz" or "Uruguay topaz", is deep brownish-yellow, clear and fiery, and is the most beautiful of the gem-stones belonging to the quartz group. There appear to be two varieties included under this name. In one, the fragments are uniformly coloured to the tips of the crystals, and the pyramid-faces sometimes show an opalescent, milky appearance: when carefully heated, this material becomes colourless, regaining its colour on cooling. The other variety comes in more columnar pieces which are colourless at their tips, the end faces being dull and white. In both of the varieties dichroism is not noticeable. Although described as burnt amethyst, they have not the characteristic optical characters of amethyst; plates cut perpendicular to the principal axis behave like rock-crystal and yellow quartz and show an intergrowth of right-handed and left-handed quartz. It is probable that we have here stones which were originally brown, but in which the colour has been improved by burning. Such material comes from Brazil and Uruguay, and fetches 20—50 marks per pound.

"*Spanish topaz*" is a perfectly clear, light yellowish-brown stone, and the rich colour is combined with a strong fire, so that this variety gives a fine gem-stone. As distinct from the "brown topaz", it occurs as large crystals bounded by prisms and pyramids, and is strongly dichroic — pale yellow for the ordinary ray and yellowish-brown for the extraordinary. The fine colour seems to be the result of a careful application of heat, the original colour of the stones being brown. This variety is found at Hinojosa in the Spanish province of Cordoba, on the northern slopes of the Sierra Morena, and it is also said to come from New Zealand. Of all the brown and yellow varieties of quartz, it is the most expensive, clear stones of large size costing £25 per pound.

All these yellow and brown "topazes" are extensively employed as precious stones, and especially those of a deeper colour and brilliant lustre. They are readily distinguished from the true topaz by means of their specific gravity: when placed in methylene iodide or in bromoform topaz sinks, while all the varieties of quartz float.

Amethyst is a violet quartz, the colour being a pale or deep violet with a tinge of red or of blue. The nature of the colouring matter is not known; manganese and iron compounds have been suggested, but the question has not yet been decided. The change in colour which amethyst undergoes at high temperatures is also still open to discussion. It is usually stated that amethyst becomes yellow when heated, and that at a temperature of 250° C. it is completely decolorized. This, however, does not agree with a few experiments made by the author. Pale and dark violet amethyst was gradually heated in an oven, a temperature of 290° C. being reached in about three hours, when the colour was a dull greyish-violet; and on cooling again the stones regained their original pure violet colour. The same result was obtained when the material was raised to a low red-heat. Only after prolonged ignition in a platinum crucible over the full flame of a Teclu-burner did the stones become colourless, and yellow on cooling.

The dichroism of amethyst is always very feeble, scarcely any difference being noticeable in the two images seen in the dichroscope, although one is perhaps slightly more reddish and the other more bluish.

The colouring is often very irregular in its distribution in one and the same crystal: lighter and darker patches may be irregularly distributed, or darker coloured "pyramids of growth" (p. 41) may extend from certain faces. The latter distribution of colour is shown in plate 56, fig. 8, which represents a plate cut from a crystal perpendicular to the principal axis, three sectors being violet and the three alternate sectors

almost colourless. The optical structure of such a plate as seen in parallel polarized light is represented in text-fig. 205. The three pale coloured sectors are seen to be clear with a dark line down their middle marking the junction of the two halves of respectively right-handed and left-handed quartz. On the other hand, the coloured sectors show in polarized light a close and repeated interlamination of right-handed and left-handed quartz, giving rise to the rippled appearance so characteristic of amethyst. This interlamination often gives rise to delicate striations on the rhombohedral faces, which run parallel to the edges of intersection of the alternate larger faces P, as shown in text-fig. 206; and it is also the cause of the characteristic ripple markings on the fractured surfaces of amethyst. In convergent polarized light, the paler coloured sectors give the interference-figure peculiar to quartz (plate 4, fig. 2); and the deeper coloured sectors, at points where the intermixture of right-handed and left-handed quartz is very intimate, give the interference-figure of an ordinary uniaxial crystal (plate 4, fig. 1), but at points where thicker layers are superimposed Airy's spirals are seen.

We thus see from an optical examination of sections of the crystals that amethyst consists of an intergrowth of right-handed and left-handed quartz; and the same is also shown, though only rarely, by the distribution of the trapezohedral faces on the crystals. The crystal represented in plate 53, fig. 4, and idealized in text-fig. 206, consists of a twin intergrowth of a right-handed crystal with a left-handed crystal, as already explained on p. 264. Most crystals of amethyst are, however, very simple in form, and frequently they show only an apparent hexagonal pyramid, several crystals being closely crowded together on a matrix of agate with only their tips projecting from the surface. Such crystals are often broken away from the matrix before being exported from Brazil, and are sold by auction at Idar as amethyst tips. The isolated crystal shown in plate 56, fig. 1, has no doubt been so broken from a druse, as suggested by the irregular fractured surfaces at the sides. That the apparent hexagonal pyramid is really a combination of two rhombohedra is clearly shown in plate 56, figs. 3 and 5, where the faces of one rhombohedron are large and those of the other rhombohedron are small; and again in fig. 2, where the faces of one set are smooth and the alternate faces are rough. In fig. 2 the apex of the crystal is truncated by a rough surface with approximately the position of the basal plane. In figs. 4, 6, and 7 prism-faces are also present; in the last of these the prism is unusually long and has a slight spiral twist; this crystal, further, shows a tendency to the form known as sceptre-quartz, the amethyst being grown on the end of a thinner rock-crystal with enclosures. Other pecularities of growth met with in amethyst resemble those seen in rock-crystal and smoky-quartz: in plate 56, fig. 6, we have the same hopper-shaped depressions on the rhombohedral faces as on the rock-crystal in plate 2, fig. 8; and in plate 2, fig. 9, we see amethyst surrounded by a shell of rock-crystal. Twinned crystals with bright and dull areas on the rhombohedral faces (as in plate 53, fig. 1) also occur in amethyst, but these are more frequent in rock-crystal. The most usual form of amethyst crystals is the apparent hexagonal pyramid (plate 56, fig. 1), and these are never found of the enormous size sometimes met with in rock-crystal and smoky-quartz.

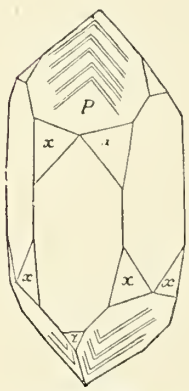

Fig. 206.
Twin-crystal (Brazil twin) of Amethyst.

Occurrence. — Amethyst is usually found in the vesicular or amygdaloidal cavities of volcanic rocks, the crystals resting on a layer of agate which coats the walls of the cavities. It so occurs in arc amygdaloidal melaphyre at Oberstein on the

Nahe in Germany, and more abundantly in Uruguay and Brazil (plate 56, figs. 2, 3, and 5). From the latter countries enormous amygdales with the interior lined with amethyst crystals are sometimes imported, but usually the material offered for sale consists of fragments and isolated crystals tips. In recent years beautiful crystals of amethyst bounded by faces on all sides and sceptre-formed crystals have been sent from Uruguay; these show a very irregular distribution of colour, being deep violet or colourless in parts, and they contain numerous enclosures of haematite, goethite, or rutile; and they are further of special interest in showing optically the simple structure of rock-crystal.

At some other localities amethyst occurs in veins traversing granite, then forming columnar aggregates or clusters of crystals bounded by prism- as well as pyramid-faces: for example, at Mursinsk in the Urals (plate 56, fig. 3), and Schemnitz in Hungary. Large crystals with hopper-shaped depressions on the faces (plate 56, fig. 6) and long prismatic crystals (fig. 7) are found in the Zillerthal, Tyrol. In North America, amethyst, sometimes suitable for cutting, is found at several localities, for example, in Iredell Co., North Carolina (plate 56, fig. 1), but these occurrences are of little importance as compared with those in South America.

With the weathering of the enclosing rocks the amethyst is set free, and is found with other pebbles in the beds of streams and rivers. Such water-worn masses, though dull and grey on their exterior, are often perfectly clear and beautifully coloured when cut, and they often yield the finest material, such as found in Brazil and Ceylon.

Application. — Amethyst has been used as a precious stone from very early times. As far back as the Mycenaean epoch it was engraved as gems and worn as amulets. It was considered as a preventive of intoxication, the Greek name amethystos meaning "not drunken".

The value of the stone depends on the depth of the violet colour and on the size of the clear pieces. Small fragments cost only five shillings per pound, while larger clear pebbles fetch fifty shillings per pound; selected pieces are worth £10 per pound, and the very best material fetches as much as £50 per pound. As with the other coloured semi-precious stones, the actual value at any time depends very much on the prevailing fashion. The stones are usually cut in the trap or step form, and are worn in brooches, pins, necklets, rings, etc. Amethyst has, however, the drawback that its colour does not show to advantage by lamplight, being then an unattractive greyish-violet. On the other hand, the "oriental amethyst" (that is, violet corundum) is a fine violet by lamplight, but this is a much rarer and more valuable stone.

Common quartz. When cloudy and with little transparency, quartz is distinguished from the preceding varieties as common quartz; and of this several varieties are also recognized, according to the colour of the material or any special colour effects. The crystal-form is always very simple, showing either the apparent hexagonal pyramid alone (plate 52, figs. 1, 5, und 6), or this in combination with a shorter or longer hexagonal prism (figs. 3, 4, and 9). Sometimes the crystals are completely developed on all sides, and they were then embedded in the matrix (figs. 5 and 6), or they carry faces at only one end, being attached to the matrix at the other end. Although simple in external form, the crystals are frequently complex in their internal structure. Frequently, the crystals are built up of layers with different degrees of transparency (fig. 11), and in some instances the alternate layers consist of right-handed and of left-handed quartz. Sometimes there is only a slight cohesion between the layers, and the crystals may be easily separated into shells, as in the so-called capped quartz (figs. 12 *a* and *b*) where one part fits exactly on another.

The colouring of common quartz is very varied, more especially in the compact and fibrous varieties. In plate 52 we see crystals ranging from almost colourless to nearly black, from pale yellow to a deep brownish-yellow, while others are pale rose-red, brownish-red, or red. In cases of this kind the colouring matter is due, as already mentioned (p. 265), to the presence of foreign material enclosed in the crystals: the black to organic matter, the red to ferric oxide, and the yellow and brown to hydrated ferric oxide. The green colour of massive quartz is due in some cases to nickel compounds.

Whilst the lustre of rock-crystal is characteristically vitreous, that of common quartz is sometimes greasy, and in the fibrous varities it may be silky.

The hardness of quartz exceeds that of most other common minerals; and for this reason wind-borne grains of sand exert a considerable wearing action on rocks, as is especially to be observed in deserts. It is well known that sharp-edged crystals and fragments of quartz are capable of scratching glass. When two pieces of quartz are vigorously rubbed together sparks are produced and a peculiar smell is often noticeable. This phenomenon is a result of the high degree of hardness; small fragments which become detached being raised to a glowing heat by the friction, and the smell is probably due to the burning of organic matter enclosed in the quartz.

Common quartz is the most abundant of all minerals, being met with at almost all places on the earth's surface. Attached crystals are of frequent occurrence in veins and in cavities of rocks, occurring either alone or in company with other minerals, for example, with felspar, plate 1, fig. 1, or with haematite, plate 52, fig. 1. Such veins and cavities lined with quartz crystals are met with in rocks of almost all kinds, with the exception of those of recent formation; for example, in granite (plate 1, fig. 1), gneiss and mica-schist, greywacke (plate 52, fig. 11) and sandstone, limestone and marl, and iron-stone (plate 52, fig. 1); and even the cavities in fossils of sedimentary rocks are sometimes lined with quartz crystals. Embedded crystals of any appreciable size are, on the other hand, of less frequent occurrence; these are found more especially in limestone (plate 1, fig. 8), in gypsum, and in quartz-porphyry (plate 52, fig. 5). The crystals embedded in quartz-porphyry are frequently rounded and corroded, as shown in the sections in plate 59, figs. 3 and 4.

As irregular grains, quartz is especially abundant as an essential constituent of rocks of many kinds of rocks; together with felspar and mica it forms granite and gneiss, with mica it is present in mica-schist, and as grains held together with a cementing material in sandstone and quartzite, while as loose grains it forms the sand of the sea-shore and sand-dunes. Quartz is in fact the most important of the rock-forming minerals. In many rocks the presence of quartz may be recognized by the unaided eye, whilst others must be examined as thin sections under the microscope. As seen under the microscope, quartz is always fresh and unaltered, colourless and transparent, and it frequently contains enclosures of liquid or of the ground-mass (plate 59, fig. 3). In thin sections of porphyritic rocks the quartz usually shows six-sided outlines often rounded and invaded by the ground-mass (plate 59, fig. 4). In granitic rocks the quartz grains are quite irregular in outline, the material usually filling the spaces between the other minerals. Owing to the low index of refraction, the surface of quartz in thin sections appears smooth; and the double refraction being also low, polarization colours of the first order are shown between crossed nicols (at least in very thin sections — in thicker slices colours of higher orders will be visible).

The localities for common quartz are without number; a few which yield the better crystals are mentioned in the explanation of plate 52.

Applications. — The common and abundant quartz-sand has many useful technical applications. It is largely used in the manufacture of glass, being fused with soda or glauber-salt, potash or lime. Easily fusible glasses contain soda and lime, and ordinary bottle-glass contains some iron; variously coloured glasses are made with the addition of metallic oxides (cobalt for blue, copper for red, etc.); and strongly refracting glass contains lead. A systematic and scientific study of different kinds of glass has in recent years been made by the firm of Schott in Jena; and the composition of the product has been varied to suit different conditions, for example, for use in thermometers, prisms, lenses for telescopes, microscopes, etc. Quartz is also used in the preparation of soluble glass (water-glass), hydrofluosilicic acid, etc. On account of its hardness, quartz is used as a sand-blast for producing dulled patterns on glass and stone. In the marble industry quartz-sand is used in sawing the blocks into thin slabs. With slaked lime it gives the extensively-used morter.

According to differences in colour and structure, the following varieties of common quartz are distinguished: —

Rose-quartz is a massive quartz of a delicate rose-red shade of colour, which is found at Zwiesel in Bavaria and a few other localities. The colour fades on prolonged exposure to light, and it is probably due to some organic compound. Crude imitations are sometimes made by immersing heated rock-crystal in water and allowing colouring matter to penetrate into the fissures so produced. Rose-quartz is sometimes cut into small spheres and other ornamental objects.

Eisenkiesel or *ferruginous quartz* is an opaque quartz brightly coloured red by ferric oxide or yellow by hydrated ferric oxide. Red crystals (plate 52, figs. 8 and 9) are found embedded in gypsum and aragonite at Santiago de Compostela in the north of Spain and are known as "Compostela hyacinth". Compact, red ferruginous quartz is found in association with diabase in the neighbourhood of Dillenburg in Nassau; and red material intermixed with white quartz from the Hessian village of Löhlbach is known as "Löhlbach agate". The red and white stones engraved as gems in Mycenaean times, and often referred to as jasper, are more probably eisenkiesel with intermixed white quartz. Yellow, and also red, eisenkiesel occurs as a secondary product in the middle Devonian limestone in the neighbourhood of Iserlohn in Westphalia (plate 52, fig. 10).

Avanturine is a variety of quartz showing a glittering, spangled effect, caused by the enclosure of numerous minute scales of mica or haematite. The same effect is displayed to a greater extent by the artificial avanturine-glass made on the island of Murano near Venice; in this the light is reflected from the surfaces of microscopic crystals of metallic copper, which by a secret process have been made to separate out in the glass.

Fetid quartz, or stink-quartz, is a name applied to quartz rich in organic material, which when struck or rubbed emits a smell of burning. Crystals of this variety are found in the Muschelkalk at Pforzheim in Baden (plate 52, fig. 7).

Radiated quartz, or star-quartz, a white quartz with a radially columnar structure, is found at Hohenelbe in Bohemia, Adorf in Waldeck, Warstein in Westphalia, and other localities.

Cat's-eye (plate 52, figs. 15 and 16) is a translucent quartz enclosing numerous, very fine fibres of asbestos or actinolite which are arranged parallel to one another. This finely fibrous structure gives rise to a peculiar reflection from the surface of the stone; and when the stone is cut and polished with a convex surface, the base of which is parallel to the fibres, the reflection takes the form of a band of light which moves across the surface as the stone is turned about. The ground-colour may be greenish-

grey, bluish, yellow, or brown; the most valuable stones being those of a yellow colour with a sharply defined band of bluish-white. This chatoyant effect shown by quartz cat's-eye is due to the same cause as in the very similar but more valuable stone known as cymophane or oriental cat's-eye. The latter is a variety of chrysoberyl (p. 235) and may be readily distinguished from quartz by its greater density and hardness. The best specimens of quartz cat's-eye come from Ceylon, but cloudy pieces are also found at Hof in Bavaria and at Treseburg in the Harz.

Tiger-eye (plate 52, fig. 14), is a finely fibrous quartz coloured bright yellow by the intermixture of a large amount of hydrated iron oxide (limonite). The fibres though parallel in their arrangement are frequently wavy or sharply bent. On a polished surface the stone shows a highly lustrous, golden yellow reflection, which changes in intensity as the stone is moved about in the hand. First introduced some thirty years ago, it has been so extensively cut as pin-stones, umbrella-handles, small boxes, and many other small objects, that the market is now almost flooded with the material.

Tiger-eye is not a mineral of primary formation, but owes its origin to the alteration of the blue asbestiform mineral crocidolite (plate 66, fig. 8), a silicate of sodium and iron, which is also known as blue asbestos, With the weathering of this mineral the sodium is carried away in solution, the iron is oxidized and hydrated to limonite, and this together with the silica preserves the fibrous form of the original mineral. Tiger-eye is thus really a pseudomorph of quartz and limonite after crocidolite. An intermediate stage in the alteration is represented in the so-called *hawk's-eye* (plate 52, fig. 13), in which the stone has been hardened by the separation of the silica, but without the oxidation and hydration of the ferrous oxide. The yellow and blue colours are sometimes associated together in the same stone, giving an opportunity of carving representations of fishes, pheasants, etc. When ignited, tiger-eye becomes red, and such burnt stones are occasionally cut. Hydrochloric acid extracts the colouring iron compound, and the stones so decolorized will absorb other colouring matters from solutions. Material coloured in this way with red, blue, or green aniline dyes has unfortunately been extensively offered for sale, but the bad taste of the purchaser is soon brought home to him by the fading on exposure to light of these most inappropriate colours.

The mineral occurs in narrow veins which traverse a ferruginous quartz-rock in the Asbestos Mountains near the Orange River in South Africa. It is got out as slabs, and the fibres are disposed approximately perpendicular to the surfaces which formed the walls of the vein.

Prase is a columnar quartz coloured green by enclosed fibres of actinolite: it is found at Breitenbrunn in Saxony. Although much employed by the ancient Romans for engraved gems, it now scarcely ever used.

Hornstone is a compact, grey or yellowish quartz with a splintery fracture, the splinters being translucent like horn. It is always of secondary formation, occurring as fissured nodules in weathered rocks, or as a pseudomorph after various minerals.

Chrysoprase (plate 52, figs. 18 and 19) is a hornstone coloured green by a nickel compound. The splintery fracture is distinctly shown in fig. 18 by the paler coloured reflection from cracks near the surface. The colour is not very stable, being destroyed at quite a low temperature. It is therefore probable that the colour is due to a hydrated nickel silicate, which loses water and consequently its colour when heated. Like hornstone, chrysoprase is a secondary mineral; it is found, together with chalcedony, in crevices in serpentine at Kosemütz and Baumgarten near Frankenstein in Silesia. The stone is cut and polished with a convex surface and mounted on pins,

or plates are used in mosaics. Recently, much chalcedony artificially coloured by chromium has been placed on the market, and it is difficult to distinguish this material from true chrysoprase.

Jasper is a name which has been in use from very early times, and it was probably formerly also applied to grey chalcedony and nephrite. It is now applied to red, opaque, dull stones which strictly speaking are rocks rather than simple minerals, since they consist of a mixture of different minerals. The intermixture is, however, so intimate that the several constituents cannot be recognized even under the microscope; but chemical analysis shows that the material is not pure quartz. The amount of quartz present varies widely and may be as low as 80 per cent., the remainder of the material consisting of ferric oxide, clay, compounds of ferrous oxide, and organic matter. The typical *red jasper* is the *ball-jasper* from the pisolitic iron-ore district of Auggen in southern Baden; with it, and often in the same specimen, is associated a *yellow jasper*, the red material forming the interior of the balls and the yellow the exterior. *Green jasper* is found at Orsk on the Ural River above Orenburg, and is cut in Ekaterinberg. *Brown jasper* is found as nodules, rounded and polished by blown sand, in the desert near Cairo, and is known as Egyptian jasper. *Riband-jasper* is a quartz-schist with bands of green, brown, and red from the Urals and the Harz Mountains. The bluish-grey *porcelain-jasper* is a clay baked by the burning of coal, and *basalt-jasper* is a clay baked by molten basalt. The former of the varieties of jasper, with their compactness and uniformity of structure, are especially suited for engraving, and they have been used for gems since a early period, the uniformly red stones being especially admired by the Romans. At the present day they are mostly used in Florentine mosaics, or are worked as boxes, bowls, plates, and other objects. The ancient Babylonian cylinder-seal shown in plate 40*a*, fig. 1, is cut in a red and white striped jasper (or perhaps eisenkiesel, compare p. 273).

Tridymite.

In striking contrast to the large and clear crystals of quartz, crystals of tridymite are small and quite inconspicuous. The two substances, though both composed of silica (SiO_2), differ in crystalline form and other characters. Crystals of tridymite have the form of thin, six-sided plates (plate 54, fig. 14), and may be either simple or interpenetration-twins; in size they rarely exceed a few millimetres across, crystals as large as those represented in the figure being quite rare. They are dull and cloudy with a greyish or yellowish colour (the green colour of the crystals shown in the figure is due to a thin coating of chlorite). The specific gravity is considerably lower than that of quartz, being only 2·3. Tridymite is a much less stable form of silica than quartz, and it frequently occurs changed into quartz. The crystals represented in the figure, though possessing the external form of tridymite, have the specific gravity of quartz, and under the microscope are seen to consist of an aggregate of irregularly orientated grains of quartz: they are in fact paramorphs of quartz after tridymite.

Tridymite occurs in the cavities of volcanic rocks, especially trachytes. Localities are the Euganean Hills near Padua (plate 54, fig. 14), the Siebengebirge near Bonn, Mont Dore in the Auvergne, and San Cristobal near Pachuca in Mexico. It has also been recognized in meteorites and described under the special name asmanite.

Chalcedony and its Varieties.

Chalcedony is one of the few minerals which, though crystalline, never presents any external crystal forms. It occurs only in stalactitic (plate 58, fig. 10), botryoidal, or reniform (plate 58, fig. 9) shapes; in the interior it shows a finely fibrous structure and splintery fracture, and small splinters of the material are translucent. The fibres are so very fine and so closely packed together that they can only be recognized when thin sections of the mineral are examined under the microscope in polarized light; the fibres are then seen to posses a radial arrangement about numerous centres. In chemical composition chalcedony is identical with quartz, but the physical characters are different, the specific gravity, for example, being rather lower (2·60), and the optical characters are not quite the same. The colour is mostly grey, bluish-grey, or yellowish, and deeply coloured varieties are distinguished by special names. Some masses of chalcedony are porous and capable of absorbing liquids, and for this reason they adhere to the tongue; other pieces are more compact and not porous. Usually the porous and non-porous materials occur repeatedly interbanded in the same specimen, the thin layers being then alternately lighter and darker in colour (plate 57, fig. 1). Unstriped chalcedony of uniform character and sufficiently porous to absorb colouring matter is known at Idar and Oberstein as "Massikstein", whilst material consisting of porous and non-porous layers is called "striped Serra-stone". These two varieties form a passage from unstriped to striped chalcedony, the well-known agate being a typical representative of the latter.

The *artificial colouring* of chalcedony, which is possible by reason of the porosity of the material, has been practised from early times. The art was for a time lost, and again came into use in Germany about the year 1820. A *black* colour is obtained by soaking the well-dried stones for some weeks in a warm, dilute solution of honey, and then, when they are completely saturated, placing than in sulphuric acid: the honey is thereby decomposed and finely divided carbon separates out in the pores of the stone. By such a process a uniform coloration is not obtained, the porous layers only being blackened, while the non-porous layers remain white, as shown in the specimens of onyx in plate 57, figs. 5 and 6. A more uniform colouring may be obtained by treating the stone with caustic potash before soaking it in honey, but even then the colour only penetrates the outer skin of the stone; material treated in this way is cut into thin slices for making black buttons. A *red* colour is produced by saturating the stone with a solution of an iron salt and then igniting. Yellowish or pale red chalcedony, which already contains some iron, also acquires a red colour when strongly heated. A *blue* colour is obtained by first soaking the stone in a solution of an iron salt and then in a solution of potassium ferrocyanide, the iron then being precipitated as Prussian blue in the pores; and according to the degree of porosity of the different layers these will be coloured a paler or a darker blue. Such blue coloured chalcedony is often sold at watering-places as lapis-lazuli, from which, however, it is readily distinguished by its translucency, greater hardness, and absence of embedded specks of iron-pyrites. Translucent chalcedony is coloured *yellow* by immersing it for a short time in hydrochloric acid. In recent years an artificially *green* coloured chalcedony has been placed on the market in large quantities, the colour here being due to chromic oxide. The stones are saturated with ammonium chromate and ignited, but the exact composition of the chromium solution, whether it is acid or alkaline, is kept a secret. Finally, chalcedony has recently been coloured a rich *brown*, the trans-

lucent stones having much the appearance of some garnets. This colour is obtained by soaking the stones in a solution of brown sugar-candy and then burning. Brown stones of this kind have been prepared and cut in large quantities during recent years, a translucent "Massikstein" of good quality being best suited to give a uniform shade of colouring.

Owing to its compactness and uniformity in texture, chalcedony has always been the principal material used in the glyptic art. According to the differences in colour and the surface patterns of the material, several varietes are distinguished. In the following description of these varieties we shall divide them into two main groups — the unstriped and the striped chalcedonies.

Unstriped Chalcedony includes the varieties:— common chalcedony, plasma, heliotrope, carnelian, and sard.

Common Chalcedony is translucent and of a grey, bluish-grey, or yellowish colour; and is the material mostly employed in the Ionic and Grecian glyptics of the fourth and fifth centuries and of all later times. The carving represented in plate 40*a*, fig. 6, is in such material. Although a mineral of very common occurrence, it is at only a few localities that large pieces of suitable quality for cutting are found. The specimens shown in plate 58, figs. 9 and 10, are from Iceland, where the mineral is found in the vesicular cavities of a volcanic rock. The delicately banded specimen in plate 57, fig. 1, is from Uruguay, which country, together with the neighbouring Brazilian state of Rio Grande do Sul, yields at the present time the largest quantity of chalcedony. In former times India was probably the chief country of supply. The chalcedony amygdales were originally formed in the cavities of an amygdaloidal melaphyre, but this rock being weathered they are now found loose in the ground; they have much the shape of a roll of bread, and may sometimes measure as much as a metre in diameter and weigh several hundredweights. Hollow, kidney-shaped nodules of chalcedony containing water in their interior are found in Uruguay, and are known as *enhydros*. Delicate, stalactitic forms of common chalcedony were formerly found in some of the Cornish mines. A smalt-blue chalcedony pseudomorphous after cubes of fluor-spar is found at Tresztya in Transylvania.

Dentrite (tree-stone) or *Mocha-stone* is chalcedony showing in one plane delicate dendritic or tree-like markings (plate 55, fig. 1; text-fig. 207). Such forms are often popularly thought to be plant remains, but they have really been formed by the percolation of a solution containing manganese along one of the layers in the stone and the deposition of manganese oxide. Similar forms may be readily produced by pressing a drop of ink between two sheets of paper or glass. The stones are so cut and polished that the marking remains covered by a thin layer of chalcedony, through which it can be clearly seen. Large and finely marked stones fetch a high price; the one shown in plate 55 was bought for £3. As a rule, however, the stones are much smaller and the patterns less delicate and plant-like, and they are then of little value; they are usually mounted in brooches and chains. The best specimens come from India, and formerly possibly from Mocha in Arabia, hence the name mocha-stone.

Fig. 207.
Dendrite or Mocha-stone.

Other markings in chalcedony may show a resemblance to gnats, as in the so-called gnat-stone from Montana.

Spotted chalcedony, or St. Stephen's stone, shows red spots of iron oxide. *Moss-agate* is a chalcedony enclosing green, moss-like aggregates of chlorite or actinolite. As

these coloured enclosures increase in amount we find a gradual passage to the coloured varieties of chalcedony.

Plasma is a chalcedony uniformly coloured leek-green by the enclosure of green-earth or chlorite; it somewhat resembles green jasper, but is distinguished from this by being translucent on thin edges. It has been supposed to be a cure for stomatic disorders. From the earliest times in Greece it has been engraved as scarabs, and by the Romans it was especially admired. Until comparatively recently this stone was known only as the material of antique gems, but we now know that similar material occurs in the volcanic rocks of the Deccan in India, and it is probable that the Romans obtained it from there. Other localities, such as Oppenau in Baden, are of little importance.

Heliotrope (plate 52, fig. 17) may be described as a plasma marked with spots of red, and since these resemble drops of blood the stone is often called *blood-stone* or blood-jasper. This also occurs in Bombay, but recently it has been found also in Brazil and Australia, and it was formerly quarried in the island of Rum in Scotland. Heliotrope was much used for engraving as gems in later Roman times and especially in the Renaissance; at the present day it is cut for pin-stones and ring-stones.

Carnelian is a red chalcedony, the most valuable material being clear and translucent and of a rich red colour. This colour is due to minute particles of iron oxide enclosed in the stone. Frequently, instead of red, the colour is yellowish-red, owing to the hydrated condition of the ferric oxide; but when such stones are ignited, and the water so driven off, they acquire the desired shade of red. From red jasper, carnelian is distinguished by its translucency, jasper being opaque. Like other varieties of chalcedony, it occurs in the vesicular cavities of volcanic rocks, and when the enclosing rock is weathered the mineral is found loose in the soil. Material suitable for cutting is quite rare. Since early times the best material has come from India, for instance, the Rajpipla Hills at Ratanpur on the lower Narbada river, and several places in the west. A South American locality from which carnelian is exported is the Campo de Maia, fifty miles south of the Rio Pardo.

In ancient times carnelian was a favourite material for engraving as gems, and material of very fine quality is found amongst the Etruscan scarabs and the gems of the Augustan period. At the present day it is also engraved or cut simply as ring-stones and pin-stones.

Sard is an early name for carnelian (antique sard) derived from Sardes, a town through which the material from India was imported into Greece. Now the name is restricted to translucent chalcedony of a pale to dark brown or almost black colour. In the fourth century before Christ it was one of the most valued of stones, but at the present day it is almost entirely replaced by the artificially coloured chalcedony known in the trade as sardonyx.

Striped Chalcedony consists of alternate layers of coloured and white material. When the bands are straight and parallel, the material is known as *onyx*, different names being used according to the colour; thus in onyx proper the bands are alternately black and white, in *carnelian-onyx* red and white, and in *sardonyx* brown and white. These names have, however, not the same meaning now as formerly. The onyx of the ancients is identical with our "oriental alabaster", that is, a fibrous and banded calcite or aragonite; sardonyx was applied to stones with alternating lighter and darker layers, our sardonyx being probably known to the ancients as aegyptilla. Nicolo is a sardonyx with opaque dark brown, almost black, layers, which was especially in vogue during the first century B. C.

Onyx proper with bands of a deep black colour (plate 57, figs. 5 and 6) is of rare occurrence in nature, and most of the material is artificially coloured; the same is true of much carnelian-onyx, which is also artificially coloured or the colour intensified by burning. The brown layers of sardonyx are also usually coloured artificially.

Specimens of the unstriped chalcedonies, carnelian and sard, are often obtained by cutting out the coloured bands of striped chalcedony, which may be either naturally or artificially coloured. And again, the different varieties of onyx do not differ essentially from agate, so that all of them may really be classed under the general term agate.

The varieties of onyx, and especially the sardonyx, have at all times afforded the best material for engraved gems. The large "Gemma Augustea" (plate 58*a*) is cut in a sardonyx of two layers; the Ptolemaic cameo (plate 40*a*, fig. 4) shows nine layers, all of which have been employed to advantage in the engraving. At the present day cameos are still cut in onyx, especially in Italy, but the majority of modern Italian cameos are really shell-cameos, being cut from the thick and variously-coloured shells of certain molluscs. The localities of the varieties of onyx, being the same as the localities of agate, will be mentioned farther on.

Agate (plate 57), the commonest and best known of the semi-precious stones, is a striped or banded chalcedony, and its characteristic appearance bears a direct relation to its special mode of origin and occurrence. It occurs principally as a filling material in the vesicular cavities of melaphyre, a rock which has consolidated from a molten lava. When the lava flowed out on the earth's surface the diminution of pressure allowed the water it contained to expand, giving rise to steam cavities in the mass; these cavities would be at first spherical, but with the flowing of the viscous mass they are often drawn out along the direction of flow and become amygdaloidal or almond-shaped (text-fig. 208). The layers of agate in an agate-amygdale follow exactly the outlines of the cavity in which they were deposited, and the aggregate thickness of the several layers is thus the same in all parts (plate 55, fig. 2, and plate 57, fig. 3).

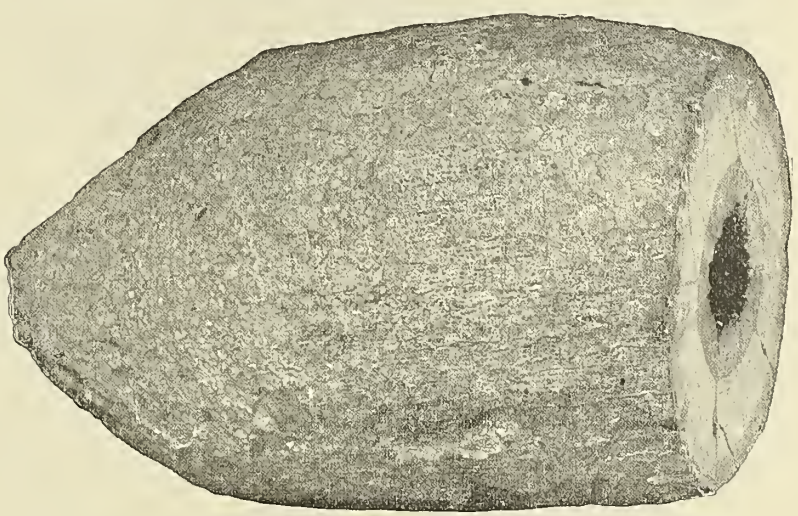

Fig. 208.
Agate-amygdale from Göttenbach, Oberstein, Germany.
Viewed from the side: $^2/_3$ natural size.

The thickness of the individual layers is often extremely small, 17,000 layers having been counted by Sir David Brewster in the thickness of one inch; usually, however, the apparent layers are much thicker than this. In consequence of this extremely fine, laminated structure, certain specimens, known as *rainbow-agate*, exhibit prismatic colours, the fine bands acting as a diffraction-grating when a plate of the agate is held up to the light: thicker pieces show a wavy reflection of light.

At certain spots the bands of agate do not run parallel to the external surface, but form a sort of channel, called an infiltration canal, through which solutions

penetrated into the cavity. During the period of growth of an agate these infiltration canals have several times changed their position; this may be seen in plate 55, fig. 2, where the latest canal is very distinctly shown, and two earlier ones are less conspicuous.

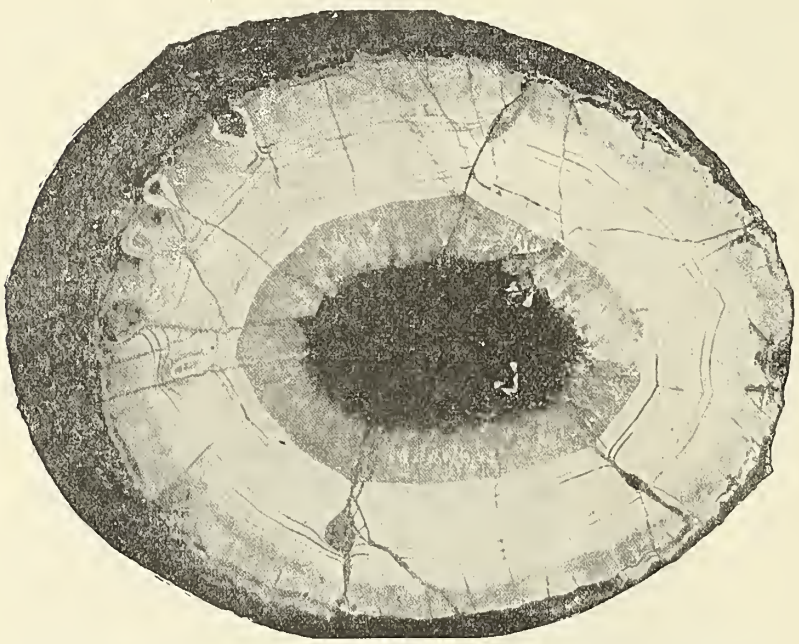

Fig. 209.

Agate-amygdale: cross-section of the specimen shown in fig. 208. Natural size.

In the hollow amygdale shown in text-fig. 209 no less than eight canals may be distinguished; and in a completely filled amygdale they are very numerous, though, of course, they are only to be seen in sections. The latest formed layer in the hollow amygdale of text-figs. 208 and 209 consists of crystallized quartz, the inner surface consisting of crystals closely crowded together and with their apices projecting into the interior of the cavity. Frequently this crystallized quartz is of the amethyst variety; and resting on it may be crystals of calcite or zeolites (harmotome, phillipsite, chabazite, etc.), or needles of manganite or goethite, which represent a still later period of growth. Between the external surface of the agate and the enclosing rock there is frequently a thin layer of a green, earthy chloritic mineral known as delessite. The rocks in which agates are found are always much decomposed.

In discussing the origin of agate-amygdales we must bear in mind the various points just mentioned. It is certain that the material was deposited from an aqueous solution, and it is probable that the solution was hot. The rock may be assumed to have been saturated with hot water, not doubt soon after its final consolidation, and this would have acted on the rock-forming minerals and taken up material in solution. That such hot solutions are present in the rocks of volcanic districts is well known, as shown by the hot intermittent springs and geysers of Iceland and the Yellowstone Park, and by the materials deposited around them. Such a solution on reaching a cavity in the rock and spreading over its walls will, partly on account of cooling and partly by evaporation, deposit some of the mineral matter it held in solution. The uniformity in thickness of each thin layer over the surface of the whole cavity is perhaps to be explained by the pressure of water vapour inside the cavity, the silica jelly being pressed and consolidated against the walls of the cavity before the next layer was deposited. The crystallization of amethyst in the interior during the later stages of formation may be due the slower rate of growth at a lower temperature. This explanation of the formation of agate is, however, not altogether satisfactory, for while the "infiltration canals" remained open there could not have been an increased pressure of water vapour inside the cavities: and we know that other some minerals (e. g.

malachite) presenting much the same structure have not been formed in districts where geysers are active. It is possible in such cases that the solution simply pentrated the walls of the cavity by capillary attraction and deposited matter from solution as a film on the surface.

Moreover, the bands of agate do not always follow the walls of the cavity. Several agates, especially those from South America, are partly built up of horizontal layers, while in the upper portion the bands follow the walls of the cavity and sometimes show intervening layers of crystallized quartz (plate 57, fig. 2). Here the cavity was no doubt partly filled with the solution and the horizontal layers deposited on the floor; subsequently there was the deposition of crystallized quartz; and finally, the ordinary type of agate formation. In other cases, stalactitic growths of chalcedony (plate 58, fig. 10) may be first formed in the cavity, and the remaining space afterwards perhaps filled up with horizontal layers of agate. In these instances the solutions were clearly influenced by gravity; the pressure of water vapour and the adhesion of a film of liquid to the walls of cavity being without effect.

According to the form of the several layers and the patterns to which they give rise, many trivial varieties are distinguished; for instance, fortification-agate, eye-agate, ring-agate, riband-agate, etc. A special variety is that known as brecciated-agate (plate 57, fig. 4), which consists of fragments of riband-agate broken up by earth movements and cemented together again by a later deposit of quartz.

The natural colouring of agates is usually only dull, pale red and yellowish layers alternating with white and grey translucent layers; and although pronounced red and brown colours do sometimes occur naturally, the bright colours of cut agates are mostly produced artificially (p. 276).

Agate of a quality sufficiently good for cutting is found at only a few localities, but then often in large amounts. Good stones were formely quarried from an amygdaloidal melaphyre in the neighbourhood of Idar and Oberstein on the Nahe in Germany (text-figs. 208 and 209), but now they are only occasionally found; these are characterized by their pure white and bluish-red layers. Veins of riband-agate and brecciated-agate occur in a quartz-porphyry at Rochlitz in Saxony; and very pretty agates, the so-called Scotch pebbles, are fairly abundant at Montrose in Forfarshire and in Perthshire. At the present day the largest amount of agate is obtained from Uruguay and the neighbouring Brazilian state of Rio Grande do Sul. Of some importance also are the Indian occurrences on the Deccan plateau, near Ratanpur on the lower Narbada river, and near Rajkot in the Kathiawar peninsula.

Some of the stones, especially the Indian, are cut in the countries where found, but the Brazilian are largely imported into Germany and cut at Idar and Oberstein or at Waldkirch in Baden. From Germany the cut material is exported to all parts of the world, and there is scarcely a watering-place of any renown where Oberstein agate goods are not offered for sale.

Application. — Agate, more than any other stone, has always been subject to the dictates of fashion, and the remark of Pliny "in magna fuit auctoritate, nunc in nulla" applies at the present day. It was in favour during the Mycenaean epoch and again at the time of Alexander the Great, but later it was unrepresented amongst the antique gems. The present flourishing condition of the agate industry began in the twenties of the nineteenth century, with the re-discovery of the methods of artificial colouring and the discovery in 1827 of the rich deposits in Uruguay, and it reached a maximum in the middle of the century. Later, tiger-eye came more into favour, and at the present time agate is much less worn as a personal ornament (in pins, rings,

etc.). On the other hand, it is now largely used for a variety of other objects, either for practical use or for ornaments. It forms, for example, an excellent material for the much used agate mortars, for the supports of the knife-edges of chemical balances and the pivots of magnetic needles. Objects of a more ornamental character include paper-weights, knife-handles, pen-holders, stick- and umbrella-handles, boxes, bowls, seals, etc. Nevertheless, the agate industry at Oberstein and Idar is still very prosperous, and visitors should not fail to see one of the cutting works (fig. 162, p. 199) and the industrial museum at Idar. The whole population is engaged in this special industry to an extent not to be seen at any other place. In addition to agate, all the other varieties of chalcedony are cut, as well as quartz, opal, and all other precious stones, with the exception of diamond.

Opal.

In external appearance, opal differs from chalcedony in the smoothness of its conchoidal fracture (plate 58, fig. 1). It is an amorphous mineral: under the microscope, it shows no trace of crystalline structure, and it is optically isotropic. The stalactitic and botryoidal forms, by which the mineral is sometimes bounded, are the result of gravitational forces and not of any force inherent in the substance itself. Usually, however, freely developed surfaces are wanting, and the material completely fills the cavities and fissures in which it was deposited.

In chemical composition, opal differs from chalcedony and quartz in containing water in addition to silica; but the water is very variable in amount, ranging from one to as much as twenty per cent. The mineral may, indeed, be regarded as a silica-jelly, which was at first soft and contained much water, but became hard on drying. The finely powdered mineral is dissolved by a hot solution of caustic potash. The specific gravity varies from 2·0 to 2·3, and the hardness is $5^1/_2$—$6^1/_2$. The index of refraction is very low, $\mu = 1{\cdot}45$. The transparency also ranges between wide limits, and the mineral may be either perfectly water-clear or quite opaque.

To judge from the characters above enumerated, opal would seen to be mineral scarcely suited for use as a precious stone, were it not for the fact that some specimens are beautifully coloured, whilst others display a magnificent play of colours such as shown by no other mineral. According to the difference in colour or play of colour, different varieties of the mineral are distinguished.

Precious opal, or noble opal, is distinguished from all the other varieties by its fine play of colours. As seen by transmitted light its colour is not a conspicuous feature, this being milk-white in Hungarian and some Australian stones, brownish-yellow in the majority of Australian, and dark blue in the Japanese. By reflected light, however, it shows brilliant flashes of green, blue, and red colours; these may be more or less uniform over a large surface (plate 58, fig. 7), or vary from point to point (fig. 5), or again, run one into another (fig. 6); while with the movement of the stone they vary from brilliant to delicate shades of colour. This peculiar play of colours, characteristic of the opal, is probably due to the presence of cracks of microscopical fineness penetrating the whole substance, at the surfaces of which the colours are produced by the interference of the waves of light passing through the stone. The phenomenon is analogous to that shown by soap-bubbles and other thin films.

Precious opal usually occurs, together with other varieties of opal, as a mineral of secondary origin in rocks of very different kinds: it is found in the volcanic rock trachyte

and in volcanic tuffs, in sandstone and ironstone; also in fossilized wood, and even as the petrifying material of fossil shells. The earliest known locality, whence probably the mineral was obtained by the Romans, is situated near the village of Czerwenitza (Hungarian, Vörösvágás), between Kaschau and Eperjes in northern Hungary. Here the mineral occurs as nests and strings in a much weathered trachyte; and the rock itself is often closely set with specks of enclosed opal, being then known as *mother-of-opal*. These Hungarian opals, which are won by a regular system of mining, are still considered the finest and best, though they are almost equalled by some Australian specimens.

In Australia, precious opal of good quality and in large amounts is obtained from the opal mines at White Cliffs in Yungnulgra Co., New South Wales. It is here found filling veins in a hard quartzose rock, and as a cementing material in sandstone; it sometimes forms the material of fossil wood, shells, and bones, and as pseudomorphs after an unknown mineral. This opal has sometimes the same pale body-colour as the Hungarian opal, and it is not inferior to this in its play of colours. Material of rather a different kind, characterized by blue and green colours extending over large surfaces, is found at several places in Queensland, for example, on the Barcoo river and Bulla creek, where it occurs as nests and strings in a brown, siliceous ironstone (fig. 6 and 7).

In Mexico, precious opal is obtained at Esperanza, to the north-west of San Juan del Rio in the state of Queretaro, but it appears to be of little importance in the European market; and the same applies to the precious opal of Honduras. A small piece of Mexican opal, with brilliant red and green reflections, is represented in fig. 8. In recent years a fine opal of a peculiar kind has come from Japan and has been cut at Oberstein: this is dark brown and opaque, but with the play of colours characteristic of precious opal.

Precious opal has long been a favourite gem-stone. Formerly, it was one of the rarer of precious stones, but since the discovery of the Australian occurrences it has been imported in large quantities, and the market is flooded with material of medium quality, though fine specimens still command a high price. The stone is almost invarially cut and polished with a rounded, convex surface, and only rarely with a flat surface. As a ring- or pin-stone it shows to better advantage when set with a border of small brilliants.

Fire-opal (plate 58, fig. 2) is a transparent to translucent opal with a brownish-red, dark or pale yellow colour; the colour being somewhat similar to that of yellow topaz, but often with a slight milky appearance. It is, however, readily distinguished from topaz, as well as from quartz, by the fact that it feels much warmer, and by its much lower specific gravity. This variety is found in a trachytic rock (fig. 2) at Villa Secca, near Zimapan in Mexico. It is usually cut with facets, and the large table facet is often slightly curved. It is a fiery and effective gem, thought not extensively used, and it fetches a good price.

Hyalite, or glass-opal, is a colourless, glassy variety. It is often bounded by rounded surfaces, being found as single drops, like tear-drops, on other minerals; or it forms a botryoidal encrustation on a rock surface (plate 58, fig. 4), sometimes so thin as to appear like a glaze on the surface. It is met with on basalt at Steinheim near Hanau, on the Limburg, Kaiserstuhl, Baden, and at Waltsch in Bohemia. Very similar to this, but with less transparency and a pearly lustre, is the pearl-sinter, or fiorite, of Santa Fiora in Tuscany.

Semi-opal, or common opal (plate 58, fig. 1), is dull, white or yellowish, and translucent only on the edges: the fracture is conchoidal. It is found in crevices in basalt at Steinheim near Hanau, and many other places. Several varieties are distinguished by special names, according to the colour or other prominent characters, and some of them are used as ornamental stones. *Prase-opal*, which owes its green colour to the presence of nickel, is found, together with the similarly coloured chrysoprase, at Kosemütz, near

Frankenstein in Prussian Silesia. *Pitch-opal*, of a dark brown to black colour, comes from Homberg in Hesse, and Telkebanya in Hungary. *Wax-opal*, distinguished by its wax-yellow colour and waxy lustre, also comes from Telkebanya. *Hydrophane* is a cloudy, brownish opal which becomes clear when immersed in water; this change being due to the absorption of water into the pores of the mineral. Certain specimens even acquire a play of colours when immersed in water: these were formerly known as "*oculus mundi*".

Wood-opal is an opalized fossil wood, in which the structure of the wood is often plainly visible (plate 58, fig. 3). Other materials consisting of opal are: the siliceous sinter or geyserite, deposited by the hot springs of Iceland and the Yellowstone Park in the United States; and diatomaceous earth, kieselguhr, or tripolite, which consists of the siliceous shells of vast numbers of microscopic algae, or diatoms. These diatoms multiply very rapidly and their remains form thick deposits of white diatomaceous earth, which is largely used commercially. Being a bad conductor of heat, it is employed as a coating for hot-water and steam pipes; and being very absorbent it is used to carry the nitro-glycerine of dynamite.

In addition to the minerals described in this section on precious stones, the following also find an application in this direction: —

Malachite, dioptase, haematite, iron-pyrites, sphene, rhodonite, the felspars (moon-stone, sun-stone, amazon-stone, and labradorite), hypersthene, diopside, spodumene, nephrite and jadeite, olivine, cordierite, prehnite, thomsonite, fluor-spar, apatite, and amber.

The first six of the above-named minerals have been already mentioned with the ores, and the remainder will be dealt with in the sections which follow. They are of more importance in other connexions than as precious stones.

Rock-forming Silicates and allied Minerals.

General.

The minerals which we have so far considered, with the exception of quartz, play no part in forming the large masses of rock of which the earth's crust is composed; they are rather, it may be said, the ornamental portions of the structure. Compared with these, the widely distributed and abundant minerals which constitute the bulk of the earth's crust are unattractive in appearance and lacking in brilliancy of colour and lustre. The precious stones may be looked upon as the princes of the mineral kingdom, the ores as the nobles, and the rock-forming minerals as the people: each of these groups are of importance, and must be considered in their turn.

A rock, as already stated (p. 7), consists of an association of different minerals. The number of minerals so associated together to form any particular kind of rock is always small; and, indeed, there is only a limited number of minerals which are of importance as constituents of the rocks which form the mass of the earth's crust.

Rocks are not only of very different kinds, but their modes of origin are also very different. Some are of igneous origin, having resulted by the consolidation of molten material. The streams of molten lava poured out by the volcanoes of the present day give rise to *volcanic rocks*, and similar rocks were formed in past geological periods. Rocks formed in this way possess many distinguishing features: they are slaggy or cindery, and are frequently largely composed of glassy material. Their minerals are often present as crystals developed on all sides, which are embedded in a more or less compact ground-mass, like the crystal of leucite in plate 62, fig. 1, and of nepheline, fig. 6. Rocks of this kind, with larger crystals set in a finer ground-mass, are said to be porphyritic in structure, and this type of structure is especially characteristic of volcanic rocks. According to the different minerals of which they are composed, the following are the more important types of volcanic rocks to be distinguished: —

Rhyolite, with quartz, potash-felspar, and biotite.
Trachyte, with potash-felspar and hornblende.
Phonolite, with potash-felspar, nepheline, and hornblende.
Andesite, with soda-lime-felspar and hornblende or augite.
Basalt, with soda-lime-felspar, augite, and sometimes olivine.
Tephrite and *basanite*, with soda-lime-felspar, leucite, augite, and sometimes olivine.
Nepheline-basalt and *leucite-basalt*, with nepheline or leucite, augite, and olivine.

Other rocks, also of igneous origin, have been formed from molten material that has not been erupted at the earth's surface, but has consolidated within the crust. These belong the group known as *plutonic rocks*, which often form large mountain masses. Having consolidated slowly under great pressure, their minerals have all been formed together, with the result that the crystals have interfered with each other's development: and we then find, instead of crystals bounded by crystal-faces, an aggregate of irregular grains of the several minerals (quartz, felspar, mica, hornblende, augite, olivine). Although rocks of this class have been formed at some depth in the earth's crust, yet they are often met with at the surface, having been exposed by denudation. The plutonic rocks are typically

granular in structure; and according to the essential minerals present, the following more important kinds are distinguished: —

Granite, with potash-felspar, quartz, and mica.
Syenite, with potash-felspar and hornblende.
Nepheline-syenite, with potash-felspar, hornblende, and nepheline.
Diorite, with soda-lime-felspar and hornblende.
Gabbro, with soda-lime-felspar, diallage, and sometimes olivine.

Where cavities and crevices have been formed in the cooling rock-mass, these usually become lined with crystals; for instance, as already mentioned (p. 9), we find in the cavities in granite, crystals of quartz, felspar, mica, rutile, sphene, etc.

The molten magma arising from the depths of the earth is always intimately intermixed with super-heated water; on the cooling of the magma this is set free, giving rise to hot vapours and solutions, which react on the newly-formed minerals of the rock-mass. It is possible that the minerals of the zeolite group have been formed in this way during the early history of the rock, though in some instances they may have been formed subsequently by the processes of weathering. The same hot solutions emanating from the igneous mass may also penetrate the surrounding rocks, dissolving and re-crystallizing a portion of their material, and so giving rise to new minerals of contact origin, such as andalusite, garnet, idocrase, spinel, etc.

The rocks exposed at the earth's surface, being subjected to variations in temperature, become more or less cracked and fissured; into these cracks water penetrates, and when it freezes the rocks are split asunder. Low forms of vegetable life become established on the rock fragments, and by their decay they supply carbon dioxide and humic acids, which, dissolved in water, exert a slow but powerful decomposing action on the minerals constituting the rock. In this way the solid rock gradually becomes transformed at the surface into loose material. This material may then be transported by running water to lower levels, and deposited in the valleys or on the floor of the sea, thus giving rise to new rock-masses. Rocks which have originated in this manner are known as *fragmentary rocks* or as *sedimentary rocks*. They are composed of water-worn fragments of minerals or of rock derived from the pre-existing rocks of the earth's surface. Examples of rocks belonging this class are conglomerate, greywacke, sand and sandstone, clay and clay-slate, marl and loam. Finely crystallized mineral specimens are but rarely met with in such rocks; though we may occasionally find crystals of calcite in sandstone, gypsum in clay, and iron-pyrites in clay-slate. It is, however, to be noted that mineral-veins, containing a variety of crystallized minerals, are frequently found traversing the older sedimentary rocks, more especially when these are near some masses of igneous rock.

The rocks of the groups so far considered can be definitely asserted to have had one or other mode of origin; but respecting those of another large group — the *crystalline schists* — we have far less information as to how they have been formed. These have a crystalline structure like that of granite, but at the same time they have a laminated structure as in the sedimentary rocks. Such rocks may originally have been crystalline eruptive rocks, which have acquired a laminated or foliated structure by reason of enormous earth pressures; or they may originally have been bedded sedimentary rocks, which, owing to the action of heat, have acquired crystalline characters. Rocks of this group include: —

Gneiss, with felspar, quartz, and mica.
Mica-schist, with mica and quartz.
Chlorite-schist, consisting mainly of chlorite.
Talc-schist, consisting mainly of talc.

In the preceding paragraphs a few of the more important types of rocks have been mentioned by name; it is not our purpose in this place to described the characters of the rocks themselves, but rather of the minerals of which they are composed.

In a coarsely crystalline rock, such as granite, the several minerals of which it is composed are visible to the unaided eye, and their characters are sufficently obvious to enable to minerals to be recognized and identified. In most cases, however, for example basalt, the individual minerals are so minute that, to the unaided eye, the rock appears to be compact and homogeneous. It then becomes necessary to examine the rock under the microscope, in order to determine the several minerals that are present. On first consideration a compact, opaque mass of rock does not appear to lend itself to microscopial examination; but when a section of the rock is cut of sufficient thinness that the material is transparent, the constituent minerals will be separately visible under the microscope.

Such *thin sections* of rocks may be prepared by the amateur himself, but a little patience and practice are required, and it usually more expeditious to have them made to order*) or to purchase them ready made from the mineral dealers. The mode of procedure is as follows. A flake of the rock, with an area of about 2—4 square centimetres, is struck off with a hammer, and this is ground down flat on one surface by means of emery or carborundum powder on an iron plate. The ground surface is then polished with very fine emery on a glass plate. The chip is then cemented, with the ground surface downwards, to a slip of glass; this being done with a drop of Canada-balsam, which is warmed on a hot metal plate until it becomes tough but not brittle. A second surface is then ground parallel to the first, and the grinding is continued until the section is quite thin and transparent; the thinner it is made the better will be the finished section. To finish off the slide, the old balsam is scraped away and a thin cover-glass cemented over with Canada-balsam.

The *microscope* used for the examination of rock-sections requires to be fitted with special accessories, which are not often supplied with the more usual pattern of microscopes, such as are used for zoological, botanical, and medical work. These accessories enable the examination to be made with the aid of polarized light, which is of great assistance in determining the characters of the component minerals of the rock (see p. 59). Such a petrographical or mineralogical microscope is represented in fig. 210. As in the ordinary type of microscope, this consists of a stand and tube with an object-glass below and an eye-piece above. Below the stage is a mirror for reflecting light upwards into the tube of the instrument. The coarse focusing adjustment consists of a rack and pinion, and the fine adjustment of a micrometer screw. In the instrument represented in the figure the stand is hinged, so that the tube of the microscope may be placed either in a vertical or in a horizontal position: when in the latter position, the instrument may be used in conjunction with a camera for taking photo-micrographs (such as are represented in plates 59, 61a, and 67). The polarizing accessories consist of two nicol prisms: one below the stage, called the polarizer, and the other in the tube of the microscope just above the object-glass, called the analyser. The polarizer can be moved up or down as required by a lever, and the analyser can be readily slid in or out of the tube. It is, however, more convenient to have the analyser placed above the eye-piece, and in the figure such an additional nicol is shown. The vibration-directions of the light transmitted through the nicols are marked by cross-wires placed in the eye-piece and visible in the field of view of the microscope. The stage is capable of rotation about the optic axis of the instrument, and, being graduated

*) The best firm for work of this kind is that of Voigt and Hochgesang, of Göttingen.

in degrees of arc, it enables the various directions in the mineral section to be accurately determined.

With such an instrument we can examine in parallel polarized light, not only large mineral sections such as are employed with the polariscope (p. 59), but also the minute mineral grains in a thin section of a rock. If, for example, the mineral is to be tested for dichroism (p. 62), the upper nicol prism is removed and the section is turned with the rotating stage over the lower nicol. If a change of colour is observed in the mineral during this rotation we known that it is dichroic; for example, biotite will display alternately light yellow and dark brown colours, and andalusite will show blood-red and pale green. This is much the most convenient method of recognizing the presence of dichroism in small mineral grains. When determining whether a mineral is isotropic or birefringent, its extinction directions, etc., the two nicol prisms must be in place, and their vibration-directions must be at right angles to one another and parallel to the cross-wires of the microscope: the examination is then said to be made between *crossed nicols* in parallel light.

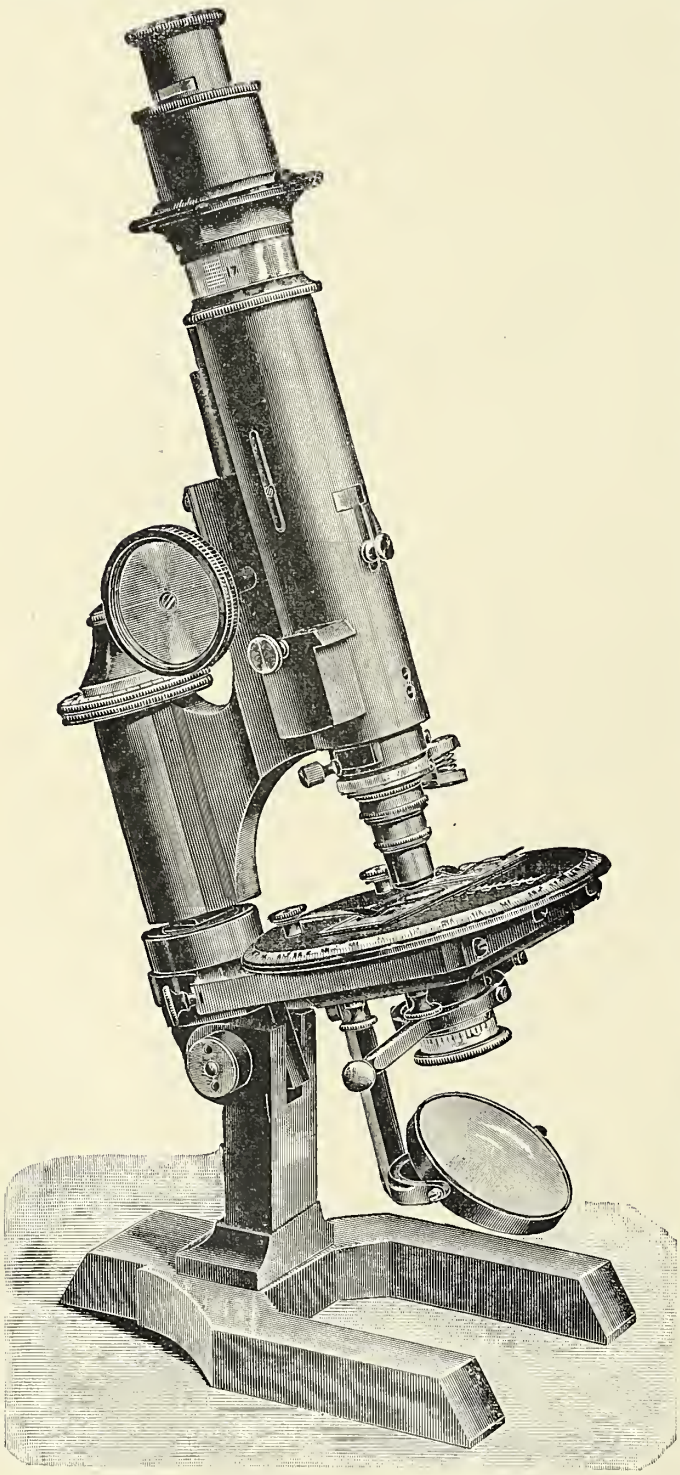

Fig. 210.
Microscope for mineralogical and petrographical work.
(By W. and H. Seibert, of Wetzlar).

The same instrument may also be used for observations in convergent polarized light. For this purpose, a system of converging lenses, called the condenser, is placed immediately below the section and above the polarizer, while above the section a high power object-glass is used. On removing the eye-piece (the two nicols being left in place) and looking down the tube of the microscope a small, but sharply defined interference-figure (p. 61 and plate 4) will be visible when a suitably orientated section is on the stage. This figure may be considerably magnified by inserting the eye-piece and at the same

time a lens (called a Bertrand lens) in about the middle position in the tube of the instrument.

On some of the preceding pages of this volume we have had occasion to call the microscope to our aid to exhibit certain structures and pecularities which are not visible to the unaided eye. For instance, the enclosures in crystals (text-figs. 96 and 97), the twinning of augite (text-fig. 103), the delicate forms of growth shown in plate 59, figs. 1 and 2, quartz with enclosures and corroded margins in figs. 3 and 4, and felspar with regularly arranged slaggy enclosures in fig. 5 of the same plate. From these observations made with the help of the microscope, we are able to draw conclusions of importance relative to the origin and mode of growth of the crystals and of the rock which they form a part. For instance, the enclosures of glass and slaggy material prove that the minerals have separated from a fused mass; the delicate forms of growth are an indication that the minerals have grown very rapidly; the corroded margins of the crystals indicate that the conditions of pressure or temperature, or that the composition of the liquid, have varied during the period that the rock was formed. Further, the structure of the rock itself is often much more obvious under the microscope than when a hand specimen is examined with the unaided eye. Thus in text-fig. 211, we see very clearly from the lines of flow that the material must once have been in a fluid state: the stream is seen to divide and pass round the square crystal on the right, and to converge and spread out again after passing through the narrow defile between the two larger crystals on the left. From our examination under the microscope of such a section we can safely pronounce that the rock from which it was cut formed part of a lava-flow.

Fig. 211.
Flow structure shown in a thin section of lava.
Magnification 45.

The study of rocks is itself a special branch of mineralogical science known as *petrography*, which owes its present-day position mainly to the examination of thin sections with the aid of the microscope. Indeed, it would not have been possible without the microscope and thin sections to have acquired our present knowledge of rocks and rock-forming minerals. Much can, however, be learnt about the minerals themselves without the aid of the microscope, for these minerals are frequently found as well-developed crystals in the cavities and crevices of rocks of which, as obscure grains, they form a part. Nevertheless, in the following descriptions we shall, where necessary, mention the characters of the rock-forming minerals as they are seen under the microscope.

Some few of the minerals which are of importance as the constituents of rocks have already been dealt with in this volume with the ores and the precious stones; for instance, magnetite, sphene, quartz, tourmaline, and zircon. On the other hand, we shall find that some of the minerals to be now described as rock-forming minerals are sometimes of importance as precious stones.

Felspar.

Felspar is a generic name for a group of minerals, similar to one another in crystalline form and analogous in chemical composition, which are the most abundunt and at the same time the most important of rock-forming silicates. In addition to silica, they contain alumina, together with either potash, soda, or lime, or mixtures of these. The several members can therefore be distinguished chemically as potash-felspar, soda-felspar, lime-felspar and soda-lime-felspar. Others containing baryta, or potash together with soda, are of less importance and need not be further mentioned in this place. Potash-felspar contains, when pure 16·9 per cent. of potash, and, being a widely distributed mineral in the rocks of the earth's crust, it supplies, when weathered, the bulk of the potash present in soils, and so affords nourishment for plants.

Although all the felspars are very similar in their general crystalline form, there is a difference in the symmetry of their crystals: some crystals possess one plane of symmetry and belong to the monoclinic system, whilst others have no plane of symmetry and belong to the triclinic system. The difference between these two kinds of crystals is, however, so slight that it is not at all obvious on inspection. The crystals of felspar represented in fig. 1, plate 60, and fig. 7, plate 61, are so similar that one would naturally conclude that they belong to the same system of crystallization; but in reality the former is monoclinic and the latter triclinic. The difference between the two kinds is more apparent when thin slices are examined in polarized light. There is also an important difference in the angle between the cleavages. All felspars cleave with ease in two plane directions: in the monoclinic felspars the angle between the two cleavages is a right angle (90°); whilst in the triclinic felspars it differs by 3° from a right angle. For this reason, monoclinic felspar is known as *orthoclase* (from the Greek, ὀρθός, right, and κλᾶν, to break), and the triclinic felspars as *plagioclase* (from πλάγιος, oblique). Potash-felspar is either monoclinic or triclinic, belonging to the species orthoclase and microcline described below; while soda-felspar, lime-felspar, and soda-lime-felspar are triclinic, these being the plagioclases described farther on under the names albite, anorthite, etc.

Orthoclase is the most important of the potash-felspars. When pure, it contains: potash (K_2O) 16·9 %, alumina (Al_2O_3) 18·3 %, and silica (SiO_2) 64·8 %, corresponding with the chemical formula $K_2O.Al_2O_3.6SiO_2$ or $K_2Al_2Si_6O_{16}$. Often a small amount of potash is replaced by an equivalent amount of soda, the potash-felspar being intermixed with some soda-felspar.

Felspar has long been a mineral of interest to crystallographers, and it is now a century ago that C. S. Weiss of Berlin used it as an illustration of his law of zones (p. 15). A crystal of monoclinic felspar (orthoclase) has already been described on p. 39 (text-fig. 83), and several actual crystals are represented on plates 60 and 61.

In the accompanying text-fig. 212 the face lettered P is the basal plane 0 P (parallel to which is the best cleavage), M the clino-pinacoid $\infty P\bar{\infty}$ (parallel to the plane of symmetry and the second cleavage), l and z are vertical prisms with the symbols ∞P and $\infty P\frac{3}{2}$ respectively, and x is a positive ortho-dome $P\bar{\infty}$. The large crystals shown in fig. 1 of plate 60 and fig. 1 of plate 61 are bounded by the same forms, and differ only in the relative length of the prism faces; in the latter crystal the faces of the prism z are coated with green chlorite.

In text-fig. 213 we have again the base P, the clino-pinacoid M, the unit prism l, a steeper ortho-dome $y = 2\ P\bar{\infty}$, and in addition a clino-dome $n = 2\ P\breve{\infty}$ (truncating the edge between P and M), and a small positive hemi-pyramid $o = P$. This crystal pre-

sents a prismatic habit in the direction of the edge between P and M, while in fig. 212 the crystal is prismatic along the edge between M and l. The four faces of P and M give a square prism. An actual crystal of this habit is shown in fig. 2, plate 60, where in addition there are narrow faces of the prism $z = \infty P 3$.

Crystals of orthoclase are usually large enough to allow the angles between their faces to be readily measured with the contact goniometer. The angle between two adjacent prism faces l is $118^3/_4{}^0$, that between the base and the adjacent ortho-dome x (fig. 212) $129^3/_4{}^0$, while from the base to the ortho-dome y (fig. 213) the angle is $99^3/_4{}^0$. The angle between the base and the clino-pinacoid is exactly 90^0, and between the base and the clino-dome n it is $135^0\ 3'$ (not 135^0, as would be the case if the edge between the faces P and M were symmetrically truncated). The faces P and x (fig. 212) are almost equally inclined to the vertical, the angle between these and the front prism-edge being respectively $116^0\ 3'$ and $114^0\ 14'$ respectively. With the help of the angles here given it is possible to identify the prominent faces on a sufficiently large crystal; and any other smaller faces can then be determined from their position in zones on the crystal.

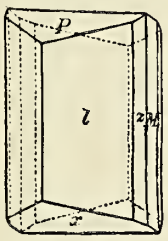

Fig. 212.

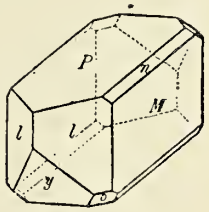

Fig. 213.

Crystals of Orthoclase.

Although simple crystals of felspar are of common occurrence, yet twinned crystals are perhaps still more common. The different types of twins are named after the localities at which they were first found.

Carlsbad twins were long ago collected at Carlsbad in Bohemia by Goethe, and were described by him in the following words: "There are large masses of the Carlsbad granite in which are found perfect crystals of very complex form. These are double crystals, consisting of two crystals so interlocked that it is impossible to consider one without considering the other. A description of their form is not sufficient to bring it to the imagination, though they may be considered as two rhombic tables united into one another." A glance at figs. 3—5 of plate 60 will suffice to show how well these double crystals were described by Goethe. We can only add that the plane which the two intergrown crystals possess in common is a plane truncating the obtuse edge of the vertical prism. This plane — the ortho-pinacoid — would, if present on the crystals, lie to the side in the three crystals in plate 60 and to the front in text-fig. 214, truncating symmetrically the edge between the two prism-faces lettered m. The twin-plane is thus the ortho-pinacoid, a face which is of comparatively rare occurrence in orthoclase. A characteristic feature of Carlsbad twins is the fact that the basal planes (c) of the two individuals of the twin slope away from the summit in opposite directions. In figs. 3—5 the basal planes are the longer faces sloping to the left and to the right, while the shorter more steeply inclined faces belong to the ortho-dome $y = 2\ P \breve{\infty}$. In other twinned crystals in which we have the ortho-dome $x = P \breve{\infty}$, instead of the steeper ortho-dome y, this plane and the base (c) fall together in almost the same plane, since, as already pointed out, the faces c and x are almost equally inclined to the vertical. This coincidence of different faces is shown in text-fig. 215 and in figs. 6—8 of plate 60. A difference in surface character is, however, to be noted between the two portions of what is apparently a single face: in fig. 8 the basal plane is white,

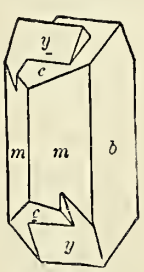

Fig. 214.

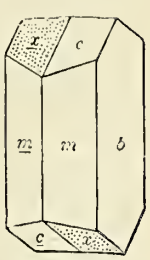

Fig. 215.

Carlsbad twins of Orthoclase.

while the nearly coincident x face is red; in fig. 7 it is lighter (on the right); and in fig. 6 it is of a purer yellow (the left-hand portion of the large face).

Baveno twins of orthoclase were first found in clefts in the granite of Baveno, on Lago Maggiore in northern Italy; twinned crystals from this locality are represented in figs. 9—11, plate 60. These crystals present the same square prismatic habit as shown in text-fig. 213, the base and the clino-pinacoid being the predominating forms: they are always attached to the rock at one end, while at the free end they show a very obtuse angle with the twin-suture running diagonally across. The twin-plane is a face of the clino-dome $n = 2\ P\ \breve{\infty}$, which truncates the edge between the base and the clino-pinacoid (text-fig. 213): and we can imagine such a crystal cut into two by a plane parallel to n, and one half rotated on the other half through 180° about on axis perpendicular to this plane.

Baveno twins of rather a different type are seen in adularia, a variety of orthoclase from the Alps. A simple crystal is represented in fig. 1, and a complex twinned crystal consisting of several individuals in fig. 2, plate 61. In fig. 3 the small crystal in the centre is twinned on both the upper and the lower portions according to the Baveno law: the two larger portions are thus related to are another by a twice repeated Baveno twinning, or they may equally well be considered to the twinned on one another according to the Manebach law.

Manebach twins derive their name from Manebach in Thuringia. Here the twin-plane is the base, and the prism faces usually form a prominent re-entrant angle on the compound crystal (fig. 12, plate 60; figs. 3 and 10, plate 61). If, however, the prism faces are small, the ortho-domes will extend to the twin-junction and produce a salient angle, as shown in the lower part of fig. 10, plate 60, and in the lower crystal in fig. 8 of the same plate.

These three kinds of twins met with in orthoclase are not confined to the particular localities from which they receive their names. From Baveno in Italy we have, for example, Carlsbad twins (fig. 8, plate 60), Baveno twins (figs. 9—11), and Manebach twins (fig. 12); and, indeed, it is possible to have all three twin-laws represented on the same hand-specimen.

The *cleavage* of orthoclase, as in all the felspars, is a character of considerable importance. There is a perfect cleavage parallel to the basal plane, and a rather less pronounced cleavage parallel to the plane of symmetry; the angle between the two cleavages being 90°. In translucent crystals the perfect cleavage gives rise to a characteristic pearly lustre on the basal plane. In fig. 1, plate 61, the cleavage cracks running across the prism faces are due to the basal cleavage, being parallel to the basal plane (at the back of the crystal; the large face at the top of the crystal being the ortho-dome). A cleavage flake parallel to the basal plane will show on its surface the traces of the second cleavage; and if such a flake be examined in the polarizing microscope between crossed nicols, the light will be cut out when these traces are parallel to the vibration-directions of the nicols. The extinction is therefore said to be straight, and we then know that we are dealing with a monoclinic felspar possessing a plane of symmetry. With other felspars, in which there is no plane of symmetry, the extinction on a basal cleavage is not parallel to the second cleavage, but is oblique.

The hardness of orthoclase is 6 (being taken as No. 6 on Mohs's scale of hardness). The specific gravity varies between 2·5 and 2·6, according to the purity of the material. The refractive indices do not exceed 1·525, and the double refraction is also low. Thin splinters of the mineral are fusible before the blowpipe, but only with difficulty.

Orthoclase is widely distributed as a constituent of various kinds of rocks, and it also occurs as well-developed crystals attached to the walls of rock cavities. According

to its mode of origin and occurrence, it presents certain differences in its external appearance, and it is usual to distinguish the varieties now to be described under the terms common felspar, sanidine, and adularia.

Common felspar (plate 60), or simply felspar (i.e. orthoclase-felspar), is cloudy and dull, and in colour may be white, yellow, grey, flesh-red, brick-red, or greenish-grey. Sometimes, as in the felspar of Fredriksvärn in Norway, it shows a change of colours, similar to that to be described farther on under labradorite. Orthoclase occurs as an essential constituent of granite, syenite, porphyry, and gneiss; and it is also present as water-worn grains in some sedimentary rocks (e.g. arkose). In granites it is mostly present as irregular grains; but in certain granites and in porphyries there are larger crystals of felspar set in a finer grained ground-mass consisting of felspar with other minerals. When the rock is weathered, these porphyritic crystals can sometimes be easily picked out from the soft, decomposed mass; figs. 2—5, plate 60, show crystals which have been isolated in this way. The mineral also occurs as crystals in drusy cavities in granites and pegmatite-veins or in clefts in gneiss; the crystals here growing out from the surface of the rock with their base rooted, as it were, in the material of the rock. Such attached crystals are shown in figs. 1, 6—9 and 12 of plate 60; while the crystals in figs. 10 and 11 have been detached from the matrix on which they grew. The large crystal represented in fig. 6 is of special interest in that it shows the yellow potash-felspar (orthoclase) surrounded by a margin of white soda-felspar (albite), the two minerals having grown together in parallel position to form one crystal.

Orthoclase is very liable to alteration by weathering, giving rise to clay, kaolin, or potash-mica.

Common felspar has certain ecomonic uses. On account of the potash it contains, it is sometimes employed as a fertilizer. Larger quantities are used in the manufacture of porcelain and pottery. In the year 1899, Norway alone produced 19,260 tons of felspar; and recently a large deposit has been opened up at Bedford near Kingston in Ontario.

Sanïdine. The orthoclase of the younger volcanic rocks (trachyte and phonolite) is a glassy variety known as sanidine. The crystals found attached to the walls of cavities in these rocks are colourless, clear and transparent, with the appearence of glass, and are therefore sometimes known as ice-spar; these are usually quite small, and are not suitable for representing in a picture. More frequently, sanidine is found as embedded crystals. These are colourless, grey, or yellowish, and are often much fissured; they may be prismatic in habit (text-fig. 213), or present the form of tabular Carlsbad twins (text-fig. 214). A fairly large crystal of sanidine, picked out from the trachyte of the Drachenfels in the Siebengebirge, Rhine, is shown in fig. 4, plate 61. On a freshly fractured surface of this rock many smaller crystals of sanidine are seen by the light reflected from their bright cleavages. Large, water-clear fragments of sanidine are found loose in the soil in the neighbourhood of Hohenfels, near Gerolstein in the Eifel; and these were formerly so abundant that they were collected for the porcelain works.

The optical characters of sanidine are of especial interest. The optic axial angle (i.e. the angular distance between the black brushes seen in convergent polarized light, fig. 4, plate 4) is different in different crystals, and the plane of the optic axes is sometimes parallel, and sometimes perpendicular, to the plane of symmetry of the crystal. Further, when a crystal is heated, a progressive change can be observed in the positions of the optic axes, and beyond a certain temperature the change is permanent. These observations indicate that the crystals have at one time been strongly heated and suddenly cooled; a conclusion which accords with the occurrence of sanidine bombs in loose volcanic tuffs. It is probable that the sanidine bombs represent a deep-seated, coarse-grained

sanidine-rock, fragments of which have been brought to the earth's surface by volcanic explosions.

Andularia. The purest crystals of orthoclase are those which occur in crevices in the crystalline schists of St. Gotthard; and this variety consequently receives its name from the neighbouring Adula Mountains in Switzerland. Three large crystals are represented in figs. 1—3, plate 61; they are transparent to translucent, and white or yellowish in colour. Sometimes, certain faces, especially those of the prism $\infty P 3$, are dusted over with green chlorite (fig. 1, plate 61). This crystal (fig. 1) shows in addition large faces of the unit prism ∞P, across which run cleavage cracks parallel to the basal plane; and the large ortho-dome face $P \bar{\infty}$ at the top. The twinned crystals (figs. 2 and 3) have already been referred to (p. 292). The adularia which occurs in the clefts of silicate rocks of the Swiss and Tyrolese Alps is usually associated with crystals of quartz, sphene, chlorite, and other minerals.

Certain specimens of adularia, particularly those from Ceylon, when held in a certain position with respect to the light, exhibit a strong bluish-white reflection comparable with the soft light of the moon. This variety is consequently known as *moon-stone*; and when good, clear specimens are cut and polished with a convex surface (en cabochon) they form a pleasing gem-stone.

Microcline. This is another kind of potash-felspar so similar to orthoclase in external appearance that the two can only be distinguished by an examination of thin flakes or sections under the polarizing microscope. The two are identical in chemical composition and specific gravity, but whilst orthoclase belongs to the monoclinic system, microcline belongs to the triclinic system. Being a triclinic felspar, a flake of microline parallel to the perfect basal cleavage does not give straight extinction (p. 292) between crossed nicols. Furthermore, between crossed nicols it shows a very characteristic grating-like or cross-hatched structure (fig. 2, plate 61a), which is not met with in the other felspars. This peculiar structure is due to repeated lamellar twinning in two directions.

In the colour, habit, and appearance of the crystals, microcline resembles orthoclase very closely. Some crystals are, however, of a bright green colour, and this variety is known as *amazon-stone* or amazonite: the cause of the green colour is not known. The four well-developed crystals of microcline represented in figs. 8—11, plate 61, are of the amazon-stone variety. As in orthoclase, these crystals are bounded by a pinacoid (which must here be called the brachy-pinacoid), vertical prisms, the basal pinacoid, and a macro-dome. It will be seen that the form of fig. 8 compares very closely with that of the crystal in fig. 1 plate 60. In fig. 11 the crystal is bounded below by the large basal cleavage, the large face above being the macro-dome. In fig. 10 we have an excellent Manebach twin: the re-entrant angle is formed by the prism faces, and the faces above and below these are the ortho-domes, the smaller being $y = 2 P \bar{\infty}$ and the larger $x = P \bar{\infty}$; while at the top is the smaller basal plane parallel to which is the twin-plane. Baveno and Carlsbad twinning is also met with in microcline; and, indeed, it is possible that the crystals represented in figs. 7 and 11, plate 60, may be microcline, for it is not always easy to distinguish between orthoclase and microcline, nor is the distinction of much importance.

Microcline occurs under exactly the same conditions as common felspar (orthoclase), and it has the same technical applications. The bulk of the Norwegian felspar quarried for porcelain manufacture is without doubt microcline. The green amazon-stone is found in the Pike's Peak district of Colorado (figs. 8—11, plate 61), and also in the Ilmen Mountains on the eastern side of Lake Ilmen in the Urals. On account of its colour it is sometimes used for ornamental purposes and for inlaying in mosaics. Ancient Egyptian amulets cut in amazon-stone have been found on rare occasions. In Russia it

was formerly used to guard against epilepsy, a rounded piece being inserted in the upper arm. This use of the stone is perhaps to be explained by a confusion with the green nephrite, which even to the present day is regarded by the Chinese as a holy stone; further, it must be remembered that formerly the name amazon-stone was applied not only to green felspar but also to nephrite.

Albite, or soda-felspar, is chemically analogous to potash-felspar, differing from it in containing sodium in place of potassium. When pure, it is composed of soda (Na_2O) 11·8 %, alumina (Al_2O_3) 19·5 %, and silica (SiO_2) 68·7 %; but almost invarially small amounts of potash and lime are present. The chemical formula is $Na_2O . Al_2O_3 . 6\,SiO_2$ or $Na_2Al_2Si_6O_{16}$. Not only in chemical constitution, but also in the form of the crystals, there is a striking similarity between soda-felspar and potash-felspar: the lie of the faces is much the same, and there is only a slight difference in the angles between corresponding faces; and the modes of twinning are similar. In soda-felspar, however, the crystals do not possess a plane of symmetry, and they are consequently triclinic.

In the crystal of albite shown in text-fig. 216 the two faces *T* and *l*, which together form a vertical prism corresponding with that of orthoclase, are different in character and here belong to different crystal-forms. *M* is the brachy-pinacoid, *P* the basal pinacoid, *x* a macro-dome, and *o* a pyramid; each of these forms consists of only a pair of parallel faces (one of each being visible at the front of the crystal). The faces *P* and *M* are inclined to one another at an angle of 93° 36′ (the corresponding angle *P M*

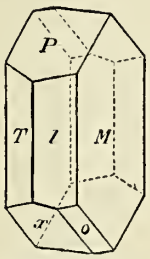

Fig. 216.
Crystal of Albite.

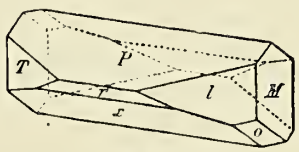

Fig. 217.
Crystal of Albite (variety Pericline).

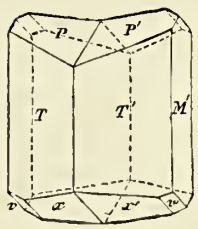

Fig. 218.
Twinned crystal of Albite.

in orthoclase being 90°). The crystal shown in text-fig. 217 presents the same faces, with the addition of a steeper macro-dome *r*; the difference in habit being here due to the greater development of the crystal in the direction of the macro-axis *b*. Albite of this habit is known as *pericline*: the crystals usually show signs of a peculiar kind of twinning, the presence of which is indicated by oblique striations on the face *M*.

Crystals of the usual habit (text-fig. 216) are invariably twinned according to what is known as the *albite-law* (text-fig. 218). Here the twin-plane is the face *M*, and one half of the twin is turned through 180° about a normal to this plane with respect to the other half of the twin. The result of this is that the basal planes of the two portions of the twin (*P* and *P′* in text-fig. 218) are inclined at an angle of 7° 12′, forming a re-entrant angle at one end of the crystal and a salient angle at the other end. A rotation about the normal to *M* in orthoclase would result in the coincidence of the faces *P* without any re-entrant angle, since here the angle *P M* is exactly 90°. This albite twinning is a specially characteristic feature of albite, and being often repeated in one and the same crystal it gives rise to a lamellar twinning, which is rendered evident by the fine striations on the basal plane parallel to the edge between *P* and *M*. Twinned crystals of albite are represented in figs. 5 and 6 of plate 61. The crystals may also be twinned according to the Carlsbad-law in addition to the albite-law.

Crystals of albite are usually only small. They may be either colourless and water-clear or white: the name albite refers, in fact, to the typical white colour. The specific gravity is 2·62 to 2·65, and the hardness 6 to $6^1/_2$. Being a triclinic mineral, the extinct between crossed nicols is oblique on all the faces, as also on a basal cleavage flake. The material is not attached by hydrochloric acid.

Albite is usually found as crystals attached to the walls of crevices in crystalline rocks, and is often associated with rock-crystal and chlorite. Sometimes it occurs as a parallel growth on crystals of orthoclase (fig. 6, plate 60). A few localities in the Alps are: the Nolla (fig. 5, plate 61) and Mt. Scopi in Switzerland, Schmirn and Zillerthal in Tyrol, Rauris in Salzburg (here the pericline variety), and Baveno on Lago Maggiore. Other localities are: Striegau (fig. 6, plate 60) and Hirschberg in the Riesengebirge in Prussian Silesia, Radauthal in the Harz (fig. 6, plate 61), Mursinsk in the Urals (as globular aggregates with smoky-quartz, fig. 10, plate 54), Kasbek in the Caucasus, Pike's Peak in Colorado (with amazon-stone, fig. 10, plate 61), Amelia in Virginia, etc.

Anorthite, or lime-felspar. This kind of felspar is, as a rule, very similar to albite in appearance, being found as small, colourless or white crystals with essentially the same form as albite, though sometimes bounded by a profusion of bright faces. Anorthite is, however, distinguished by its higher specific gravity of 2·74—2·76, and by the fact that it is decomposed by hydrochloric acid. The two minerals may also be readily distinguished by their optical characters. For this purpose a thin cleavage flake, taken parallel to the basal plane, is placed on the stage of the polarizing microscope, and the extinction angle is measured with respect to the cleavage cracks which intersect the flake parallel to the brachy-pinacoid. With albite the light between crossed nicols will be extinguished when one or other of the cross-wires is inclined at about 4° to the brachy-pinacoid cleavage cracks, whilst with anorthite this angle is about 40°. This difference may be expressed by saying that the extinction on the basal plane is more oblique in anorthite than in albite.

In chemical composition there is an important difference between albite and anorthite: in the latter we have lime in place of soda, and moreover a much lower percentage of silica. The theoretical composition of anorthite is: silica (SiO_2) 43·3 %, alumina (Al_2O_3) 36·6 %, and lime (CaO) 20·1 %, corresponding with the formula $CaO.Al_2O_3.2SiO_2$ or $CaAl_2Si_2O_8$.

Crystals of anorthite are found in the ejected blocks of Monte Somma, Vesuvius, and at Monzoni in southern Tyrol. It is much more frequent as grains in certain basic eruptive rocks, such as gabbro; and it has also been detected in meteorites.

Soda-lime-felspars. Between soda-felspar and lime-felspar there is a series of intermediate felspars with the same general characters as albite and anorthite, and the whole of these (together with the extreme members albite and anorthite) are included in the general term *plagioclase* (p. 290). These are extremely rare as well-developed crystals bounded by faces, but as irregular grains they are widely distributed as constituents of eruptive rocks. Their most characteristic feature, by which they can be recognized, is the fine twin striation on the basal cleavage. This is due to a repeated or lamellar twinning according to the albite-law, the individual lamellae being often no thicker than a sheet of paper. Each lamella is in twinned position with respect to the lamellae on either side of it, whilst the first is in parallel position with respect with the third, fifth, seventh, etc. These striations are often visible with the aid of a hand-lens, and sometimes to the unaided eye (fig. 13, plate 61). In this figure it will be seen that the striations are parallel to the edges of the fragment bounded by the second, less perfect cleavage. On account of this structure the plagioclase felspars are sometimes known as *striped felspars.*

This banded structure is rendered still more evident when a basal cleavage flake, or a thin section of the material, is examined in the polarizing microscope between crossed nicols (fig. 1, plate 61a). In certain positions the different lamellae appear as alternately light and dark bands; and on rotating the section together with the stage, the light bands become dark and the dark bands become light. If the bands be set parallel to one or other of the cross-wires in the microscope they will be seen equally illuminated; on rotating the stage through a certain angle to the right the alternate bands of one set become dark, and on rotating through the same angle to the left those of the other set become dark. The magnitude of this angle of extinction depends on the relative proportions of soda-felspar and lime-felspar present in the specimen under examination. A long series of careful observations, particularly those made by the late Professor Max Schuster, have demonstrated that an optical examination of this kind will give us an indication of the chemical composition of the felspar.

The results of chemical analyses have proved that the plagioclase-felspars can be ranged in a continuous series starting from albite and ending with anorthite, and that any one member of the series is to be regarded as an isomorphous mixture of the two extremes. Those containing up to 26 % of lime-felspar are included under the term *oligoclase*, up to 50 % *andesine*, up to 76 % *labradorite*, and those with up to 96 % are known as *bytownite*. With an increase in the amount of lime there is a corresponding decrease in the amount of silica: albite contains 68·7 % of silica, oligoclase 62 %, andesine 56 %, labradorite 49 %, and anorthite only 43·3 % of silica. Similarly, there is along the series a progressive variation in the magnitute of the extinction angle on the basal cleavage: in oligoclase this is only about 1°, increasing in andesine to 5°, in labradorite to 17°, and in anorthite to 37°. The same variation is also observed in the specific gravity, which increases progressively with the percentage of lime: the specific gravity of albite being 2·624, of oligoclase up to 2·659, andesine to 2·694, labradorite to 2·73, and of anorthite 2·758. Providing the material is quite fresh, it is thus possible to determine from the specific gravity which member of the series we are dealing with.

These intermediate plagioclase-felspars are common constituents of igneous rocks of various kinds, being often present as irregular grains (as in diorite and gabbro), or as porphyritic crystals set in a finer grained ground-mass (as in basalt and diabase). The porphyritic crystals of lavas often contain slaggy enclosures which are sometimes arranged in a zonal manner (fig. 5, plate 59) showing the stages of growth. A zonal structure of the larger crystals is also often rendered evident by the extinction angles; the nucleus, containing more lime-felspar, has a wider extinction angle, and the outer zones, successively richer in soda-felspar, have smaller extinction angles.

The felspars of coarsely crystalline rocks sometimes contain regularly arranged enclosures of other minerals which impart a special kind of lustre or colour to the host. Thus, the so-called *sun-stone*, a variety of oligoclase from Tvedestrand in Norway, contains large numbers of small, extremely thin scales of haematite, which give rise to a red colour and glittering lustre in the stone. The effect is the same as that seen in avanturine (p. 273), and this variety of felspar is consequently also known as avanturine-felspar. The labradorite or *labrador-spar* of the coast of Labrador contains vast numbers of minute scales and needles, which are doubtless the cause of the brilliant play of colours. The stone itself is of a dull smoky-grey colour, but when it catches the light at a particular angle the surface suddenly lights up with brilliant metallic colours — blue, green, red, or bronze — as but inadequately represented in fig. 12, plate 61. Labrador-spar, particularly that from Labrador, is cut and polished for jewellery and various small ornamental objects, and it is also used for inlaying.

By the alteration of the soda-lime-felspars there may be formed other minerals containing water in addition to the constituents of felspar, which, in a way, may be regarded as hydrated felspars. These form a special group of minerals known as the zeolites to be considered later. Further, when subjected to weathering processes they frequently give rise to calcite, and often to epidote, albite, and quartz: the calcium they contain forms calcite or epidote, the soda-felspar gives albite, while the excess of silica separates as quartz, chalcedony, or opal.

Felspathoid Minerals.

Certain minerals composed of the same chemical elements as the felspars and occurring in the same manner as rock constituents are known as felspathoid minerals. These differ from the felspars in the form of their crystals and they belong to distinct mineral species. We have leucite corresponding with potash-felspar, nepheline with soda-felspar, and scapolite with lime-felspar and soda-lime-felspar. In addition, there are other minerals chemically allied to nepheline, but containing also other salts, namely sodium chloride in sodalite, and sodium or calcium sulphate in nosean, haüyne, and lapis-lazuli. The last of these has already been considered with the precious stones (p. 258).

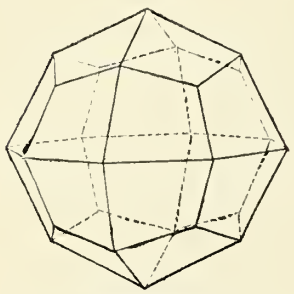

Fig. 219.
Crystal of Leucite.

Leucite occurs only as crystals, and these being always of the same form, they are a very characteristic feature of the mineral. This form is the icositetrahedron $2O2$ of the cubic system (figs. 1—3, plate 62, and text-fig. 219), which for the above reason is sometimes known as the leucitohedron. Such constancy of crystalline form, or rather habit, is met with in scarcely any other mineral species; on the other hand, some other mineral species, e. g. sphene, are remarkable for the great variation in the form of their crystals.

But although we find this very simple relation in leucite, yet it is a mineral which presents certain difficulties. The form naturally suggests a cubic crystal, which should, of course, be singly refracting. A thin section of a leucite crystal when placed between crossed nicols does not, however, remain dark, but shows the complex structure illustrated in fig. 3, plate 61a. This section is cut approximately parallel to a cube face of the crystal, and as eight faces of the icositetrahedron are intersected, the outline is an octagon. We see in the section a system of light and dark bands approximately at right angles, and others with a diagonal position: the bands are either narrow or wide, sometimes slightly divergent, and they abruptly cease when they meet one of the irregular cracks which intersect the crystal. A comparision of this complex banded structure with the more simple banding shown by sections of plagioclase felspar (figs. 1 and 2, plate 61a) suggests that it is due to repeated twinning. Further, on consideration, it is clear that the banding must be parallel to the faces of the rhombic-dodecahedron. But in a cubic crystal the rhombic-dodecahedron, being a plane of symmetry, cannot be a plane of twinning, and furthermore, as already mentioned, a cubic crystal should not be doubly refracting.

The most satisfactory explanation to this apparent contradiction is that put forward by the late Professor Carl Klein. He found that when a crystal of leucite is raised to a temperature of low redness, the lamellar structure and the double refraction suddenly disappear, the crystal being there truly cubic in its optical behaviour. On cooling again the original conditions reappear without any alteration in the external form of the crystal.

The change which here takes place is quite analogous to the change of monoclinic sulphur to rhombic sulphur (p. 141), only in leucite the external form of the crystal is not thereby destroyed. The substance of the leucite crystal is cubic only at a high temperature, while at the ordinary temperature it is tetragonal or perhaps rhombic.

Now it is an interesting fact that leucite is found only in lavas and that it is one of the first minerals to crystallize from the molten material. The mineral has thus crystallized at a high temperature in a cubic form, and, as the rock cooled, it underwent a molecular transformation and acquired the characters which we observe at the ordinary temperature. We thus have a paramorph (p. 51) of a special kind, in which the material of the crystal passes from one modification into another when the temperature reaches a certain definite point, and returns again to its original state when the temperature falls. Dimorphous substances which are related to one another in this peculiar manner are known as *enantiotropic*. Another example amongst minerals is given by boracite, which will be described farther on. The same kind of change can be observed in certain artificial salts, such as ammonium nitrate and silver iodide, by using a polarizing microscope fitted with a heating arrangement.

As seen in thin sections under the microscope, leucite presents some other points of interest. It frequently shows enclosures of glassy or slaggy material arranged in a regular manner parallel to the boundaries of the crystal (fig. 4, plate 61a). As may be seen in the several crystals here shown in section, the enclosures vary considerably in their size, shape, and arrangement.

The external appearance of the crystals is well represented in figs. 1—3, plate 62. They are white, grey, or yellowish, and when embedded in the rock they are dull and cloudy; on the other hand, the more rarely occurring attached crystals are clear with a glassy aspect. The refractive index is low (1·508), the specific gravity 2·46, and the hardness $5^1/_2$—6.

Chemically, leucite contains the same constituents as potash-felspar, but these are combined in different proportions. The composition of the pure mineral is potash (K_2O) 21·58 %, alumina (Al_2O_3) 23·40 %, and silica (SiO_2) 55·02, corresponding with the formula $K_2O.Al_2O_3.4SiO_2$ or $KAlSi_2O_6$. There are thus two molecules less silica than in potash-felspar. The mineral is liable to alteration, taking up water and soda and passing into analcite. Owing to the large amount of potash it contains and to the ease with which it weathers, an attempt has been made to use leucite as a fertilizing material in soils.

Leucite occurs as a constituent of certain recent volcanic lavas and ashes, being especially abundant in the products of Vesuvius (fig. 4, plate 61a, and figs. 1 and 2, plate 62); and at Rocca Monfina near Naples (fig. 3, plate 62). Loose crystals, from the lavas of the extinct volcanoes of the Albanian Hills, can be collected in large numbers at the Osteria del Tavolato on the Via Appia near Rome. It is also found, together with nosean, in the lavas of the neighbourhood of the Laacher See in Rhenish Prussia (fig. 3, plate 61a), at the Kaiserstuhl near Freiburg in Baden, and at Wiesenthal in Saxony.

Nepheline is essentially a sodium aluminium silicate, the formula for which may be expressed as $Na_8Al_8Si_9O_{34}$, or perhaps more simply as $NaAlSiO_4$. The composition is, however, never quite constant, and a small portion of the soda as invariably replaced by potash. Analyses also often show the presence of small amounts of lime, water, and chlorine, but whether these are chemically combined or present as mechanical impurities (crystals and solutions of sodium chloride have been observed as enclosures in nepheline) it is difficult to say.

The crystals are hexagonal, and are bounded by a hexagonal prism and the basal pinacoid (fig. 5, plate 62), sometimes with small pyramid planes in addition (fig. 4). Cross-sections of the crystals, as seen in thin slices or on fractured surfaces of the rock

(fig. 5, plate 61a, and fig. 6, plate 62) are rectangular or six-sided. The fresh mineral is colourless and transparent with a glassy lustre, but when weathered it becomes cloudy with a dull white or yellowish colour. The index of refraction is low (1·54), and the double refraction is also feeble. Only rarely are the crystals so large as those represented in plates 61a and 62. Usually they are of microscopic dimensions; and in some cases, where the external form of the crystals is wanting, the mineral can only be detected by chemical means.

The nepheline present in coarsely crystalline rocks is of rather a special character, and this variety is known as *elaeolite*, a name derived from the Greek word for oil, in allusion to the characteristic greasy lustre of the stone. Its colour is greenish, bluish, or reddish. The bluish-grey mineral represented in fig. 7, plate 62, is elaeolite, the yellowish-grey material here shown being felspar.

Nepheline is not always an easy mineral to recognize, and, when the crystal-form or the colour and lustre afford no clue, resource must to made to chemical reactions. When the powdered mineral is warmed with hydrochloric acid it is very easily decomposed with gelatinization: and if the experiment is made with only a small quantity of acid the test-tube can be inverted without the substance being spilt. In a dilute solution of hydrochloric acid the mineral is completely dissolved. Nepheline is especially liable to alteration by weathering, giving rise usually to natrolite.

Attached crystals of nepheline are met with in cavities in the ejected blocks of Monte Somma, Vesuvius (figs. 4 and 5, plate 62), and also at the Laacher See. As embedded crystals, nepheline is widely distributed as an essential constituent of certain volcanic rocks (phonolite and nepheline-basalt); whilst the variety elaeolite is a constituent of the plutonic elaeolite-syenites of Norway, Greenland, Urals, Brazil, etc.

Greenish elaeolite has occasionally been cut as a precious stone, this being the only practical application of the mineral nepheline.

Scapolite. As we have already seen, nepheline is more complex chemically than leucite, and with scapolite the complexity is still greater. In addition to silica and alumina, the mineral always contains lime and soda in variable proportions, and also some chlorine. According to differences in chemical composition, several sub-species or varieties have been distinguished. The crystals of these are practically identical, being tetragonal with prisms of the first and second orders and a pyramid of the first order (fig. 13, plate 62), and they show, in the several varieties, only very slight differences in the angles between corresponding faces. Crystals are either water-clear or cloudy and of a white, greyish, or yellowish colour; the clear crystals are quite small, but the cloudy ones are often of considerable size. The mineral is rather susceptible to alteration, passing into epidote, albite, or mica.

The clear crystals occur in the ejected blocks of Monte Somma, Vesuvius, and of the Laacher See; and the larger, cloudy crystals in the crystalline schists of Arendal in Norway, Malsjö in Sweden, Laurinkari in Finland (fig. 13, plate 62), and other localities.

By reason of its crystalline form and chemical composition, *melilite* is a mineral which finds a place in the scapolite group. It occurs as microscopic crystals in certain basaltic rocks, in which it takes the place of felspar; in thin sections it is seen as colourless laths which give blue polarization colours. It contains more lime (32 % CaO) than any other calcium aluminium silicate.

Another closely allied mineral is *gehlenite* ($Ca_3Al_2Si_2O_{10}$), which occurs as grey tetragonal plates in crystalline limestones at their contact with igneous rock-masses. It is found at Monzoni in southern Tyrol, and the Kaiserstuhl near Freiburg in Baden.

Sodalite Group. The felspathoid minerals of this group are cubic in crystallization, and the usual form of the crystals is the rhombic-dodecahedron (text-fig. 220). They thus show a relation in form to the garnets, and some authors point also to a chemical analogy between these two groups. All contain the nepheline molecule $NaAlSiO_4$ in combination with another salt, the latter differing in the different species. Their hardness lies between 5 and 6, and the specific gravity varies from 2·2 to 2·5.

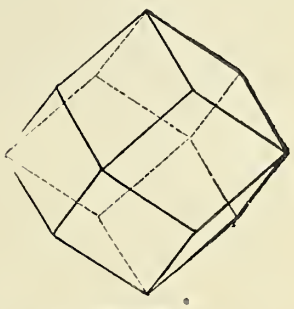

Fig. 220.
Crystal of Sodalite.

Sodalite occurs as colourless rhombic-dodecahedra in the cavities of certain volcanic rocks, particularly in the ejected blocks of Monte Somma (fig. 8, plate 62); or it forms irregularly shaped masses of a white or blue colour in certain plutonic rocks. These two varieties are analogous, in their modes of occurrence, to nepheline and elaeolite respectively, only sodalite is much less frequent. Warmed with acids it gelatinizes like nepheline; and when nitric acid is employed, the solution gives a white precipitate with silver nitrate, proving the presence of chlorine. This presence of chlorine, which amonts to 5 or 6 per cent., is the most characteristic feature of sodalite. The mineral may be considered as a chemical compound of sodium aluminium silicate with sodium chloride, the formula being $3\,NaAlSiO_4 . NaCl$.

Colourless sodalite in found in the ejected blocks of Monte Somma and as a constituent of trachyte in the island of Ischia near Naples. Massive sodalite occurs as a constituent of sodalite-syenite at Ditró in Transylvania, Brevig in Norway, Miask in the Urals, and in Greenland.

Nosean and *Haüyne.* Both of these minerals are named after mineralogists, the latter after the celebrated Abbé Haüy, the founder of scientific crystallography. They are not sharply separated from one another, and for this reason we will consider them together. Ideally, nosean is a compound of sodium aluminium silicate with sodium sulphate, and haüyne of the same silicate with calcium sulphate, their formulae being

Nosean, $3\,NaAlSiO_4 . Na_2SO_4$.
Haüyne, $3\,NaAlSiO_4 . CaSO_4$.

Neither mineral is, however, quite pure; nosean always contains some calcium sulphate, and haüyne some sodium sulphate; and further, in haüyne a portion of the sodium is often replaced by an equivalent amount of calcium. Both are readily decomposed by hydrochloric acid; and when a grain of the mineral is treated with a drop of acid on a microscope slide, and the drop allowed to evaporate, needles of gypsum will separate when haüyne has been used, whilst with nosean these will be formed in only small amount. Both minerals crystallize in rhombic-dodecahedra, and they sometimes differ in colour.

Nosean is usually brown or grey (fig. 9, plate 62); and in thin sections often colourless (fig. 6 plate 61a), but sometimes greyish, owing to the presence of vast numbers of minute gas pores, these being frequently arranged in lines and so giving the appearance of fine striations. The border is often brown and opaque and much indented by the groundmass of the rock, suggesting that the crystals were partly re-dissolved by the magma subsequent to their formation. Under these conditions, nosean occurs, together with leucite, in the phonolites of the Laacher See district, and as a constituent of certain basalts. The attached crystals are found in the ejected blocks of the Laacher See district.

Haüyne is, as a rule, blue in colour, and it is found as large, irregular masses in the millstone lavas of Niedermendig on the Rhine (fig. 10, plate 62). It is also found as small grains and crystals in the ejected blocks of the Laacher See district, in basaltic rocks

in the Albanian Hills near Rome, and in phonolite in Hegau. In thin sections the mineral may be recognized by its blue colour and isotropic character. When altered by weathering, both haüyne and nosean give rise to zeolites, especially natrolite.

Another mineral of the sodalite group, namely *lapis-lazuli* (figs. 11 and 12, plate 62), has always been described with the precious stones. The rarely occurring crystals are rhombic-dodecahedra, and this mineral shows a further resemblance to haüyne in its blue colour.

Zeolites.

The zeolites form a group of naturally occurring hydrous silicates, which, when heated before the blowpipe, swell up and give off bubbles; and it is on account of this appearance to boiling that they receive their name from the Greek ζεῖν, to boil. In addition to silica and water, all of them, with the exception of apophyllite, contain alumina together with lime or soda, or sometimes potash or baryta. They are thus analogous to the felspars in composition, with the addition of water; and, as a matter of fact, they have usually originated by the hydration of felspar or felspathoid minerals. A few of the zeolites are very simple in their form of crystallization, but others are met with only as complex twinned crystals, which by their twinning simulate higher forms of symmetry. Being minerals of secondary origin, they are found in the drusy cavities of eruptive rocks, sometimes in mineral-veins, and only rarely in sedimentary rocks.

In addition to the zeolites proper, we shall describe in this section certain other minerals which are often classified in other groups; these are also hydrous silicates with the same mode of origin as the zeolites.

Apophyllite. This name, from the Greek, has reference to the fact that the crystals exfoliate, or split up into leaves parallel to the perfect cleavage, when they are heated. The crystals are tetragonal and usually quite simple in form, being bounded by the primary pyramid *P*, the prism of the second order *m*, the base *o*, and sometimes an eight-sided prism *r* (text-figs. 221 and 222). Owing, however, to variations in the relative sizes of these faces the crystals differ considerably in appearance or habit (figs. 1—7, plate 63). The simplest form, shown in fig. 1, is bounded by the primary pyramid and the prism of the second order: the angle between adjacent pyramid faces is 104°. Fig. 3 shows the same faces, but with the prism faces relatively shorter. In figs. 2 and 4 we have in combination with these faces a large basal plane, the crystals being here thickly tabular parallel to the base. In fig. 6 we see the same faces, but here the crystal is rather thicker and the pyramid planes larger, so that the crystal has quite the appearance of a cubo-octahedron (compare text-fig. 26, p. 24); it will, however, be at once noticed that the apparent cube faces are different in character, for there is in apophyllite a perfect cleavage parallel to the basal plane. Cleavage cracks parallel to the base are shown traversing the large crystals in fig. 5: here we have the base, pyramid, prism of the second order, and also small faces of an eight-sided prism $\infty P 2$. Finally, the crystals in fig. 7 are thinly tabular parallel to the base.

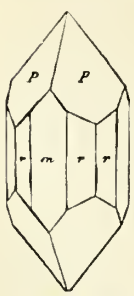

Fig. 221.

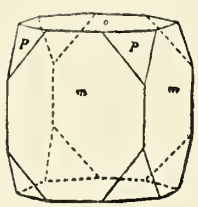

Fig. 222.

Crystals of Apophyllite.

In its chemical composition apophyllite is somewhat complex. In addition to silica, water, and lime, there is also some potash and usually a little fluorine. Half of the water is expelled at about 240° C., while the remainder, being chemically combined, is expelled only at a red-heat. The formula is consequently written as $H_2(Ca, K_2)Si_2O_6 + H_2O$. When weathered, the mineral gives rise to calcium carbonate, and sometimes the original form of the crystal is not thereby destroyed: such altered crystals are white and dull and have been called *albine*; they are found at Aussig in Bohemia.

As to the physical characters of apophyllite, mention has already been made of the perfect cleavage parallel to the basal plane. On account of this cleavage, the lustre on the basal plane and on cleavage fragments is markedly pearly in character. This whitish pearly aspect, resembling the eye of a fish after boiling, gave rise to the name ichthyophthalmite, or fish-eye-stone. On the other faces of the crystals the lustre is vitreous. A cleavage flake when examined in convergent polarized light shows the interference-figure of a uniaxial crystal, but rings are only seen when the plate is of some thickness, since the double refraction is very low. Further, the rings, as seen with ordinary daylight, are not brilliantly coloured but alternately white and violet-black; this being due to a peculiarity in the dispersion. Crystals are colourless, or pale shades of rose-red, yellow, or green. The specific gravity is 2·3 to 2·4, and the hardness between 4 and 5.

Before the blowpipe, apophyllite exfoliates and is readily fused. It is soluble in superheated water; and when the powdered mineral is heated with water in a sealed tube at about 190° C. the material can be re-crystallized. In nature the mineral must have had the same kind of origin in the cavities of volcanic rocks and in mineral-veins; while it has actually been observed as a deposit from the waters of certain hot springs.

In mineral-veins it occurs at the Samson mine at St. Andreasberg in the Harz (fig. 3, plate 63), and at Guanaxuato in Mexico. In the amygdaloidal cavities of eruptive rocks it is found at Aussig in Bohemia, the Færoe Islands, Co. Antrim, Skye, Iceland (Fig. 1), and at Paterson in New Jersey (fig. 6). The largest crystals are those formerly found near Poona in Bombay (figs. 2, 4, and 5).

Chabazite. This mineral may readily be recognized by the characteristic shape and twinning of its crystals. These are cube-like rhombohedra which are usually twinned with interpenetration, corners of one individual projecting from the faces of the other (text-fig. 223, figs. 8—10, plate 63). The twin-plane is the base, and the twin-axis, perpendicular to this, is coincident with the principal axis of the rhombohedral crystal: one individual is turned about this axis through 180° with respect to the other individual. Crystals of another habit are also commonly found: these are lenticular in shape, owing to the predominance of a low hexagonal pyramid, and are known as *phacolite*.

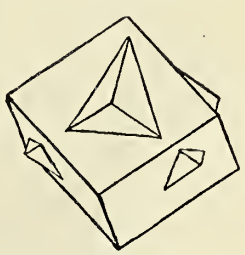

Fig. 223.
Twinned crystal of Chabazite.

Crystals of chabazite, and of its variety phacolite, are colourless, white, yellow, or red (fig. 10, plate 63); the red colour being due to enclosed ferric oxide. They have a vitreous lustre, and are frequently much fissured in their interior. Their specific gravity is 2·1, and their hardness 4—4½.

The chemical composition of chabazite is somewhat variable, and must be explained as the result of the mixing together of two compounds in variable proportions. The nature of these fundamental molecules must be deduced from the results of several analyses, and different investigators have come to different results. The following formula assumes one of these molecules to have the composition of lime-felspar, and the other that

of soda-felspar but with lime in place of soda, each molecule being combined with eight molecules of water.

$$m\,Ca_2Al_4Si_4O_{16}\,.\,8\,H_2O + n\,CaAl_2Si_6O_{16}\,.\,8\,H_2O.$$

Chabazite occurs in the amygdaloidal cavities of volcanic rocks, and is often associated with phillipsite and calcite, or sometimes with quartz and agate. It is found, for instance, in the amydaloidal basalts at Nidda and many other places in the Vogelsberg, at Oberstein in Germany, in Co. Antrim, and at Kilmalcolm in Renfrewshire. The isolated crystal shown in fig. 8, plate 63, is from the island of Sandö, one of the Færoe Islands; the crystals on phonolite in fig. 9 from Rübendörfel in Bohemia; and the red crystals in fig. 10 from Nova Scotia. The phacolite variety is found at the same localities, and also at Richmond in Victoria, Australia.

Analcite is very similar in the form of its crystals to leucite, and moreover it may be regarded chemically as a hydrated sodium-leucite. The most frequent form is the regular icositetrahedron $2O2$ (text-fig. 19, p. 23, and figs. 11 and 12, plate 63). Sometimes we find the icositetrahedron in combination with the cube (text-fig. 224). Twinning does not occur, and the crystals are thus quite simple in their form.

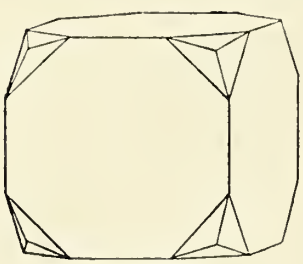

Fig. 224.
Crystal of Analcite.

The chemical composition of fresh unaltered analcite can be expressed by the formula $Na_2Al_2Si_4O_{12}\,.\,2\,H_2O$. A comparison of this with the formula of leucite ($K_2Al_2Si_4O_{12}$) shows the replacement of potash by soda and the addition of water. It is indeed possible by artificial means to convert leucite into analcite, by simply immersing the mineral for a long period in a solution of sodium carbonate. The same process also takes place in nature, for at Kaiserstuhl in Baden we find icositetrahedra which were originally leucite, but now composed of analcite. These two minerals may be distinguished by the following tests: analcite fuses before the blowpipe, whilst leucite does not; heated in a bulb-tube, analcite gives off water, whilst leucite does not; the specific gravity of analcite is 2·2, and that of leucite 2·5.

Crystals of analcite are sometimes colourless and transparent, but more usually they are white and cloudy; sometimes they are reddish, the colour being either uniform in distribution or patchy and veined (fig. 12, plate 63). The mineral occurs principally in the cavities of basaltic rocks, either alone or in association with apophyllite. Water-clear crystals are found in amygdaloidal cavities and also embedded in dolerite in the Cyclopean Islands near Catania in Sicily. Clear crystals are also found at Monti Catini in Tuscany, and Lake Superior in North America (fig. 11). Crystals of especially large size are from the Seisser Alp in Tyrol (fig. 12). The mineral is also common in Co. Antrim and at several places in Scotland. A remarkable occurrence is in clay-iron-stone at Duingen in Hannover; and it has also been found in the mineral-veins of St. Andreasberg in the Harz.

Another cubic zeolite, which may be mentioned here, is the rare *faujasite*; this occurs as small, white or brown, octahedra and spinel-twins in cavities in basalt at Grossenbuseck near Giessen in Hesse, and Kaiserstuhl in Baden.

Heulandite. Crystals of heulandite (fig. 13, plate 63) are monoclinic with usually a thick tabular habit parallel to the plane of symmetry. On this plane the lustre is strongly pearly, since parallel to it there is a perfect cleavage: the other faces of the crystals have a vitreous lustre or are dull. The large faces at the sides belong to the basal pinacoid and the ortho-pinacoid, and the small triangular faces are pyramid faces. The crystals are either white or greyish, but sometimes they are brick-red, owing to the enclosure of haematite (like the crystals of chabazite in fig. 10). The specific gravity is 2·2, and the hardness $3^1/_2$—4.

The chemical composition can here again be best expressed by reference to the felspars, and we may regard the mineral as a compound of the second lime-felspar assumed above for chabazite with five molecules of water, the formula thus being $CaAl_2Si_6O_{16}.5\,H_2O$. A portion of the lime is usually replaced by a little soda and potash, and less frequently by strontia. The mineral is readily decomposed by acids, and before the blowpipe it fuses to a white enamel.

Heulandite occurs in the amygdaloidal cavities of basaltic rock in Iceland (fig. 13, plate 63), the Færoe Islands, Scotland, and elsewhere. Red crystals are from the Fassathal in Tyrol. In veins in granitic rocks it is found on the Giebelbach in Wallis, Switzerland, and at Striegau in Prussian Silesia; and in mineral-veins at St. Andreasberg in the Harz.

Another zeolite containing the same chemical constituents as heulandite, but combined in different proportions, is *laumontite*. This is noteworthy from the fact that the crystals when exposed to the air soon fall to powder, this change being due to a gradual loss of a portion of the water contained in the crystals. Specimens must therefore be kept in a moist atmosphere over water, or they must be protected with a coat of varnish. The crystals are monoclinic with a prismatic habit and are terminated by an obliquely-placed basal plane. They are found in crevices in granitic rocks at Baveno, Zillerthal, and Striegau.

Stilbite, Phillipsite, and Harmotome. These three species of zeolites, being closely related both in crystalline form and chemical composition, may be conveniently described together in one group. The composition of the silicate portion may, as before be compared with that of the felspars, and in all three minerals this is combined with six molecules of water. Stilbite and phillipsite differ in the relative proportions of their constituents, whilst harmotome contains barium. In all of them a portion of the calcium or barium is replaced by some sodium or potassium. The formulae are: —

Stilbite . .	$CaAl_2Si_6O_{16}.6\,H_2O$
Phillipsite .	$\left\{\begin{matrix}CaAl_2Si_6O_{16}.6\,H_2O\\Ca_2Al_4Si_4O_{16}.6H_2O\end{matrix}\right.$
Harmotome .	$\left\{\begin{matrix}BaAl_2Si_6O_{16}.6\,H_2O\\Ba_2Al_4Si_4O_{16}.6H_2O\end{matrix}\right.$

From these formulae we see that chemically phillipsite differs from chabazite only in containing six molecules of water instead of eight, and that stilbite is the same as heulandite with an extra molecule of water.

In their crystallization all three minerals show a certain relation to the felspars; they are monoclinic and invariably twinned. The faces shown in text-figs. 225 and 226 are those of the vertical prism *m*, the clino-pinacoid *b*, and the basal pinacoid *c*; those of the two former are striated parallel to their mutual intersection, as indicated in the figures. The angle between the faces of the vertical prism is 118° 50′ (the corresponding angle in orthoclase being 118° 47′).

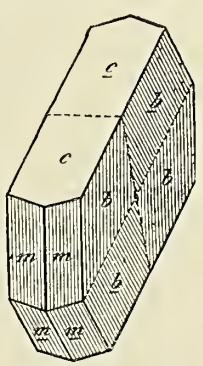

Fig. 225.
Twinned crystal of Stilbite.

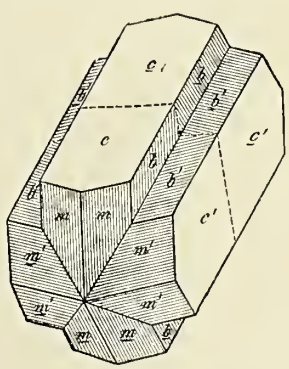

Fig. 226.
Twinned crystal of Phillipsite (or Harmotome).

The twinning is also in part analogous to that of the felspars. The three following twin-laws are to be distinguished. *First twin-law*, with the basal plane as the twin-plane (as in the Manebach twins of felspar). The two individuals are united along the basal plane,

and the two portions shown to the front in text-fig. 225 are repeated cross-wise at the back; in the figure the face letters of one individual are underlined. The clino-pinacoid coincides in the two individuals and now bears feather-like striations. Stilbite frequently occurs in crystals with this form. *Second twin-law*, with a clino-dome face as twin-plane (as in the Baveno twins of felspar). Two crystals, each already twinned according to the first law, are twinned together with interpenetration (text-fig. 226) in such a manner that a clino-dome face (a face which, if present on the crystals, would truncate the edge between the faces *b* and *c*) is coincident in the two individuals. The compound crystal produced by this double twinning presents the appearance of a tetragonal prism with grooved edges combined with a pyramid of the opposite order (compare text-fig. 178, p. 227). If the basal plane *c* be more largely developed relatively to the clino-pinacoid *b*, the latter will be suppressed, and in the absence of the grooved edges the compound crystal will appear still more like a simple tetragonal crystal. The presence of twinning will, however, always be rendered evident by the feather-like striations on the prism faces *m*. Twinned crystals of this kind are especially common in harmotome (fig. 3, plate 64) and phillipsite (fig. 2, plate 64). *Third twin-law*, with a face of the vertical prism as twin-plane. Three of the compound crystals produced by the last twin-law are now twinned together with interpenetration on two of the prism faces of one of them. The result is a complex group consisting of twelve simple individuals (text-fig. 227). When the simple crystals are of a thin tabular habit there are several re-entrant angles; but with thicker crystals and when the material so grows that the spaces are filled up, we then have a completely closed crystal, resembling a rhombic-dodecahedron, bounded on all sides by the striated prism faces (text-fig. 228). We have here an excellent example of how the degree of symmetry of a crystal may be apparently increased by twinning. The first twinning (fig. 225) produces a pseudo-rhombic crystal, the second (fig. 226) a pseudo-tetragonal, and the third (fig. 228) a pseudo-cubic crystal, and yet each of these is built up of monoclinic individuals. The presence of this complex twinning is indeed sometimes only suspected when the crystals are closely examined with a lens and the directions of the striations on the faces carefully noted.

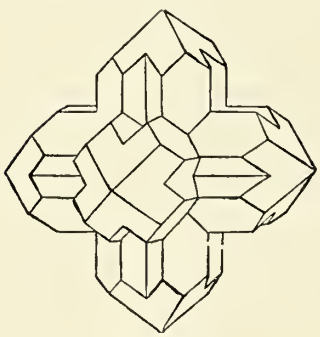

Fig. 227.

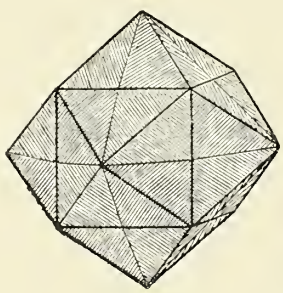

Fig. 228.

Complex twinned crystals of Phillipsite.

Stilbite is usually found as sheaf-shaped crystals or aggregates of crystals (fig. 1, plate 64), and the name desmine sometimes applied to the species has reference to this form (δέσμη, a bundle). The sheaf-shaped structure is due to a sub-parallel grouping of several of the simple twinned crystals shown in text-fig. 225. Parallel to the clino-pinacoid *b* there is a perfect cleavage on which the lustre is pearly: on other faces the lustre is vitreous. The colour is white or yellowish, or sometimes brick-red or brown. Stilbite is found in amygdaloidal cavities in the volcanic rocks of Iceland, the Færoe Islands, Scotland, Nova Scotia, etc. Brick-red crystals come from Kilpatrick in Dumbartonshire, and large pink crystals with apophyllite from Poona in Bombay. In drusy cavities in granitic rocks it is found at Striegau in Prussian Silesia, and at several places in Switzerland; and in mineral-veins at St. Andreasberg in the Harz.

Phillipsite forms complex twins of the forms shown in text-figs. 226—228; these are usually quite small, rarely exceeding 1 cm. in length. They are white or yellowish, and

either brilliant or dull; the specific gravity is 2·2. This mineral receives its name from the English mineralogist William Phillips. It is found in the cavities of basalt in County Antrim, at Stempel near Marburg in Hesse (fig. 2, plate 64), at Richmond in Victoria, Australia, and elsewhere.

Harmotome is popularly known as cross-stone, on account of the characteristic shape of its twinned crystals (text-fig. 226, and fig. 3, plate 64). In some crystals, however, when the grooves are not present, the crossed form is not evident. Since it contains the heavier metal barium, the specific gravity (2·5) of harmotome is higher than that of the other zeolites. The colour is white, grey, or yellowish, and the lustre vitreous. The crystals are usually very sharply developed and may attain a length of a couple of centimetres. Excellent crystals are found in mineral-veins at Strontian in Argyllshire, St. Andreasberg in the Harz, and Kongsberg in Norway. It is also found in agate geodes from the melaphyre of Oberstein in Germany.

Phillipsite and harmotome are extraordinarly similar in the shape of their complex twinned crystals and in external appearance generally: they may be readily distinguished by means of their specific gravity or by a chemical test for calcium or barium. To test for barium, the powdered mineral is decomposed with hydrochloric acid, and to the diluted solution a drop of sulphuric acid is added, when with harmotome a heavy white precipitate of barium sulphate is formed.

Natrolite. As implied by its name, this mineral contains the metal sodium or natrium, the chemical symbol of which is Na. The name sodalite, applied to another mineral (p. 301), has the same meaning. In addition to soda (i.e. sodium oxide), natrolite contains alumina and silica, together with water, the chemical formula being $Na_2Al_2Si_3O_{10} . 2H_2O$. The presence of sodium in the mineral is readily demonstrated by the bright yellow colour which it imparts to the colourless flame of the Bunsen-burner. A fragment of the mineral when held in the flame quickly fuses to a colourless glass, and produces the same yellow flame-coloration as that given by common salt (sodium chloride). Other characteristic chemical reactions of natrolite are the following. The powdered mineral gelatinizes when warmed with a little hydrochloric acid in a test-tube. When heated in a bulb-tube, abundance of water condenses on the cool sides of the tube.

Crystals of natrolite usually have the form of very thin and delicate needles. These are sometimes grouped in small tufts, or they may thickly encrust the surface of the rock. The crystals belong to the rhombic system; but they present quite the appearance of tetragonal crystals, since the angle of the rhombic prism differs but slightly from a right angle, being $91\,^1/_4{}^0$. Further, they are terminated by the four faces of a low rhombic pyramid, which does not differ, so far as can be judged by the eye, from a tetragonal pyramid. Frequently, however, the crystals are closely grouped together to produce compact, radially-fibrous aggregates with a rounded surface, and sometimes also a concentric shelly structure.

The colour is white or yellow, rarely red or green. In the radiating masses there is sometimes a concentric banding of different colours. The hardness is greater than 5; instances in which it is apparently less than this may be explained by the breaking away of the individual fibres of the more or less incoherent aggregate. The specific gravity is 2·2 to 2·25.

Natrolite occurs as a product of the alteration of felspar, and more especially of nepheline and haüyne; and as such it is met with in the steam-cavities of certain lavas, especially basalt and phonolite. Well-known localities are: in the phonolite of Hohentwiel in Würtemberg (plate 64, fig. 4); the Alpstein, near Sontra in Hesse; the Stempel, near Marburg in Hesse (here not now to be found); Aussig in Bohemia (plate 64, fig. 5); as large,

rough crystals at Brevig in Norway; as thick growths of delicate needles on the basalt of County Antrim in Ireland; as delicate tufts of hair-like crystals in the Færoe Islands; and as beautiful groups of distinctly-developed, water-clear crystals at the Puy de Marman in the Auvergne. Several other localities might be mentioned, natrolite being, in fact, one of the most abundant of the zeolites, though rarely occurring as distinct crystals.

The prettily coloured and banded natrolite from Hohentwiel (plate 64, fig. 4) has occasionally been cut and polished as a semi-precious stone for ornamental purposes. Being fairly hard and compact, this finely fibrous material takes a good polish. It has been used as a wainscotting in the rooms of the royal palace at Stuttgart. The German poet Joseph Viktor von Scheffel (1826—1886) has given an account of the legend of how the youth Audifax, when rooting up a bush, laid bare the yellow veins which penetrate the grey rock of the mountain.

Closely allied to natrolite are a few other zeolites which may be briefly mentioned in this place. *Scolecite* contains lime in place of soda, and the silicate is combined with three molecules of water of crystallization. Its crystals, although very like those of natrolite in form, are in reality monoclinic, but by twinning they closely simulate the rhombic form. The best crystals come from Theigarhorn in Iceland. *Mesolite* contains the chemical constituents of both natrolite and scolecite. It usually forms finely fibrous masses, which can be distinguished from natrolite only by a determination of the optical characters under the microscope. *Thomsonite* also consists of a calcium aluminium silicate and sodium aluminium silicate with water of crystallization, the formula being $(Ca, Na_2)_2 Al_4Si_4O_{16} . 5H_2O$. This zeolite usually forms radially columnar aggregates (plate 64, fig. 6); but sometimes the aggregates are finely fibrous, with a concentric shelly structure in addition to the radially fibrous. In the latter case the mineral bears a strong resemblance to natrolite (plate 64, fig. 4), although it usually differs from this in colour. Large, radially columnar masses of thomsonite, often with a delicate rosy tinge of colour, have been found at Kilpatrick in Dumbartonshire. Thomsonite showing concentric bands of lighter and darker red, green, and white colours is found in amygdaloidal diabase at Grand Marais, Lake Superior. Small pebbles of this material collected from the shore are polished for use in jewellery.

Prehnite. Although prehnite contains some water and boils up when heated before the blowpipe, it is not as a rule classified with the zeolites, since its water is expelled only at a high temperature. We may, however, consider it in this place because it occurs together with the zeolites, and has been formed like them by the alteration of felspar. If we consider the water to be present as such in the mineral, we see that the formula of prehnite presents a certain analogy to that of natrolite, the two formulae being:

Natrolite . . . $Na_2O . Al_2O_3 . 3\,SiO_2 . 2\,H_2O$.
Prehnite . . . $2\,CaO . Al_2O_3 . 3\,SiO_2 . H_2O$.

Usually, however, the formula of prehnite is written in the form $H_2Ca_2Al_2Si_3O_{12}$, in which the hydrogen is basic and plays the part of a metal. When the mineral is heated, this hydrogen is expelled in the form of water, although it does not actually exist as such in the mineral.

That prehnite is not so closely related to the zeolites as these are one to another is also suggested by the colour. Prehnite is always greenish, whilst the zeolites are characteristically colourless or white, although they are sometimes reddish or yellowish, due to the presence of mechanically admixed iron oxide or hydroxide. In prehnite, on the other hand, a small amount of iron oxide is often present in chemical combination replacing an equivalent amount of aluminia.

Crystals of prehnite belong to the rhombic system; when found, which is only very exceptionally, they usually have the form of small rhombic plates flattened parallel to the basal plane. Much more frequently the mineral forms aggregates similar to those of natrolite, with globular surfaces and a radially fibrous structure internally (plate 64, fig. 7). Fan-shaped and cockscomb aggregates of crystals are also characteristic.

The hardness is 6, exceeding that of the zeolites, whilst the specific gravity of 2·8 to 2·9 is considerably higher than for any of the zeolites.

Prehnite is found in the steam-cavities of ancient volcanic rocks and of intrusive igneous rocks, such as diabase and melaphyre. It usually occurs in association with quartz, calcite, albite, less often with datolite, and sometimes with native copper. Less frequently, it is found in veins traversing granite and gneiss. A few of the many known localities for this mineral are: Niederscheld near Dillenburg, and Friedensdorf near Biedenkopf, in Hesse-Nassau; the Radauthal near Harzburg in the Harz; the Fassa valley in Tyrol (plate 64, fig. 7); Bourg d'Oisans, Isère, France (plate 64, fig. 8); as fine specimens in the ancient volcanic rocks at several places in the neighbourhood of Edinburgh and Glasgow; as large masses at Cradock in Cape Colony, where the mineral was first found towards the end of the eighteenth century by Colonel Prehn, after whom it was named.

A peculiar mineral called *chlorastrolite* is sometimes referred to prehnite, although it is perhaps more correctly considered as a variety of thomsonite. This is found as small pebbles, the size of a pea or hazel-nut, on the shores of the Isle Royale in Lake Superior, having been washed out of the amygdaloidal trap rocks of the Island. These pebbles show on their surface light and dark green colours with a peculiar reticulated pattern similar to that on a serpent's skin. In the interior they show a finely fibrous radiated structure. They take a good polish and when cut with a rounded surface often display a kind of cat's-eye effect. They are much sought for by collectors and in America are often worn in jewellery.

Datolite. Our reason for considering datolite with the zeolites is that, like these, it is a mineral of secondary origin in the cavities and crevices of basic volcanic rocks. It also, when heated before the blowpipe, swells up, owing to the expulsion of water, though to not so marked a degree as do the zeolites. In chemical composition, however, it differs very markedly from the zeolites. Like apophyllite (p. 302), it contains no aluminium, an element present in all the zeolites; on the other hand, the elements boron and fluorine present in datolite and apophyllite respectively, do not occur in the zeolites. In its chemical formula, as also in the form of its monoclinic crystals, datolite presents a close analogy to the rare mineral euclase (p. 233). In the datolite formula $HCaBSiO_5$ calcium and boron take the place of beryllium and aluminium respectively in the euclase formula $HBeAlSiO_5$.

Crystals of datolite are usually bounded by a profusion of small, brilliant faces, and they afford excellent material for crystallographic study and measurement on the reflecting goniometer. An isolated crystal with relatively few faces is represented in fig. 9, plate 64. In this crystal the faces set vertically are prism faces; above these and to the front is a large ortho-dome face; at the sides are pyramid faces; and at the top a small basal plane. As a rule the crystals are colourless and transparent with a brilliant glassy lustre, and they occur closely crowded together forming a crystallized crust on the surface of the matrix. Such specimens are little suited for pictorial representation. Larger crystals are also found, and these are frequently tinged with green. The specific gravity of the mineral is 2·9—3·0, and its hardness 5. With hydrochloric acid it gelatinizes, like the zeolites.

Datolite is usually found as crystals lining the crevices of igneous rocks such as diabase, melaphyre, and diorite. Less often it is found in mineral-veins. Localities are:

Andreasberg in the Harz; Baveno on Lago Maggiore in the north of Italy, here as large crystals of tabular habit; Serra dei Zanchetti in the Apennines near Bologna (plate 64, fig. 9); in the neighbourhood of Edinburgh and Glasgow; Arendal in Norway; Bergen Hill in New Jersey.

Kaolin and Clay.

Kaolin. The zeolites (p. 302) may be regarded as intermediate products formed by the alteration of felspars and felspathoid minerals. As proved by experiments, this alteration may have been effected by springs of hot water or by the action of mineral solutions in the earth's crust. The zeolites do not, however, represent the final products of weathering. When felspar is exposed to the prolonged action of water and carbon dioxide, the alkalis and alkaline earths contained in it are removed, and there remains behind the hydrated aluminium silicate known as kaolin or china-clay. The complete decomposition of potash-felspar by the processes of weathering near the earth's surface is accompanied by the leaching out of the potash in a soluble form as carbonate or silicate. This is removed in solution and is of importance as affording nourishment for plants. At the same time a portion of the silica of the felspar is set free, and this often separates as quartz in the immediate neighbourhood. The remainder takes up water, giving rise to the formation of kaolin. This change may be represented in outline as follows:

Felspar	K_2O .	Al_2O_3 .	6 SiO_2
Removal of	K_2O		4 SiO_2
Addition of			2 H_2O
Residual product . .		Al_2O_3 .	2 SiO_2 . 2 H_2O.

These constituents of the residual product may be written in the form $H_4Al_2Si_2O_9$, representing the chemical formula of kaolin. It is by such a process, at or near the earth's surface, that kaolin has been formed; but in exceptional cases the larger deposits of pure kaolin may have originated by the action of hot springs containing carbon dioxide in solution.

In a pure condition kaolin is a white, earthy, and friable material, which is quite soft and light. It is plastic when moistened with water, and before the ordinary blowpipe it is not fusible. At a still higher temperature it frits together, and is then no longer capable of taking up water. It is on these characters that the use of kaolin in the manufacture of porcelain depends; and the purer the material the more suitable it is for this purpose. Crystallized kaolin, which is sometimes distinguished by the name kaolinite, is of extremely rare occurrence. It has been found in only small quantities as a white, glistening powder in rock cavities at a few localities. Under the microscope these crystals are seen to have the form of thin, six-sided scales.

Deposits of kaolin are of wide distribution in Saxony. That at Aue has been completely exhausted in supplying material for the porcelain works at Meissen. At Meissen itself kaolin occurs in conjunction with pitchstone — a glassy igneous rock — the felspar of which is in places completely weathered to kaolin. Such a crude china-clay contains, for example, 57·46 % of clay substance, 41·11 % of quartz, and 1·43 % of unweathered felspar. The purified china-clay separated from this by washing in water contains 56·15 % silica, 32 % aluminia, 10·81 % water, 0·64 % ferric oxide, 0·33 % lime, and 0·47 % potash. Deposits of china-clay are also found at Passau in Bavaria, at Morl near Halle, etc. Those at St. Yrieix in France, in Cornwall and Devon, and in China are of special importance.

Clay. The conditions under which the processes of weathering take place are such that the resulting kaolin is very liable to be contaminated with other minerals. At its place of origin it is intermixed with fragments of unweathered felspar and grains of quartz in greater or lesser amounts, these having been derived from the same weathered rock mass that gave rise to the kaolin itself. Being in a state of very fine division this kaolin is readily removed by running water, and it so becomes intermixed with quartz-sand, and various other materials of a calcareous, ferruginous, or carbonaceous nature. When such a heterogeneous mixture contains a predominating amount of the kaolin substance it is called *clay*; when sand and iron oxides are largely present it is a *loam* or brick-earth; and when calcareous material is present in larger amounts it is a *marl*. These, being mechanical mixtures, are clearly of the nature of rocks rather than simple minerals; and they only receive mention in this place because of their great economic importance. Marl, although of high value in soils, cannot, on account of its calcareous nature, to put to the some technical uses as clay and loam.

Applications of Clay and Kaolin. — From loam and impure clays bricks and tiles are made, and from clays, according to their degree of purity, the less valuable pottery, earthenware, Delft-ware, and fire-proof vessels. After shaping the clay into the desired form, it is dried and baked. When the vessel is to be impervious to water, it is coated with a material which will produce a glaze during the burning. The glaze has much the same composition as a glass, and by the addition of various metallic oxides it can be produced of any desired colour. Blue is obtained with smalt, yellow with antimony sulphide, brown and black with iron and copper oxides, and white with tin oxide. The majority of these articles being for ordinary use are of a single colour or they are painted with a rough pattern. From the same materials ornamental objects of artistic merit can be fabricated. Examples of work of this kind by Luca della Robbia and of Andrea della Robbia are to be seen at Florence; such as the valuable figures of children on the foundling hospital and the enormous reliefs of the Madonna. The highly-prized Majolica-ware is also made of clay skilfully and artistically glazed.

Fire-proof objects are made from a clay which contains no felspar, lime, or iron, and which does not fuse, but only sinters, at the highest temperature. From such material are made fire-bricks for lining furnaces, and Hessian and Passau crucibles (the latter made of a mixture of fire-clay and graphite) used in glass works and for various other purposes where high temperatures are employed.

The finest kind of ware, known as porcelain, is made from kaolin containing some admixed felspar and quartz. The objects when formed in the white china-clay are first gently baked; then immersed in water and dusted over with powdered felspar; and finally, after drying, they are raised to a white-heat. At this very high temperature the felspar becomes fused and penetrates into the pores between the particles of clay; on cooling it solidifies as a glass, so giving to the porcelain its characteristic translucency. The fire-resisting colouring materials are applied before the second burning, and some others are burnt in subsequently at a more gentle heat.

Pyroxene Group.

All the rock-forming minerals as well as their products of weathering so far considered are free from iron; and for this reason they are, with few exceptions, of pale colours. Those to be now described almost always contain iron, and they are consequently of

darker colours. On these lines we can thus distinguish between the lighter and the darker coloured rock-forming minerals. Amongst the latter there are several minerals exhibiting similarities in chemical composition and crystalline form which enable them to be classified into certain well-defined groups. The most important groups of this kind are the pyroxene, amphibole, mica, chlorite, and olivine groups. These will each be considered in turn in the arbitrary order in which they have just been named.

The minerals of the pyroxene group are for the most part silicates of magnesium and iron, and certain members of the group are composed entirely of these (enstatite, bronzite, and hypersthene). The magnesia and iron (ferrous) oxide are present in variable proportions, but their combined molecular ratios is always equal to the molecular ratio of the silica; that is, the ratio of the bases to the acid is as 1 : 1. For example, $MgO : SiO_2 = 1 : 1$, corresponding with the formula $MgSiO_3$. Other minerals of this group contain lime in addition to magnesia and ferrous oxide; and these are present in such proportions that the molecular ratio of the magnesium and iron silicate taken together is the same as that of the calcium silicate (diopside). In other members aluminia may also be present (augite), and it is usual to distinguish between aluminous pyroxenes and those which contain no aluminia. Less closely related minerals of the pyroxene group are those containing alkalis (spodumene and acmite), or lime without magnesia (wollastonite), or manganese (rhodonite). The first-named members are rhombic, the last is triclinic, whilst all the others are monoclinic in crystallization. Collecting these remarks, we may now give the following summary of the minerals of the pyroxene group:

1. Enstatite, Bronzite, and Hypersthene, $MgSiO_3$ (or $Mg_2Si_2O_6$) with a successively increasing proportion of $FeSiO_3$ (or $Fe_2Si_2O_6$): rhombic.
2. Diopside and Hedenbergite, $Ca(Mg, Fe)Si_2O_6$ with an increasing amount of iron: monoclinic.
3. Augite and Diallage, $Ca(Mg, Fe)Si_2O_6 . (Mg, Fe)(Al, Fe)_2SiO_6$: monoclinic.
4. Spodumene, $LiAlSi_2O_6$, and Acmite, $NaFeSi_2O_6$: monoclinic.
5. Wollastonite, $CaSiO_3$: monoclinic.
6. Rhodonite, $MnSiO_3$: triclinic.

Of these, rhodonite has already been described with the ores of manganese (p. 171): and the others will now be described in the order here named. Their relation to the amphiboles will be discussed in that group.

Enstatite, Bronzite, and **Hypersthene** consist of isomorphous mixtures of magnesium silicate with ferrous silicate in varying proportions. Enstatite contains up to 5 per cent. of ferrous oxide, bronzite 5 to 15 per cent. and hypersthene 15 to 30 per cent. The pure magnesium silicate would contain theoretically 40 per cent. magnesia and 60 per cent. silica; and the pure ferrous silicate 54·4 per cent. ferrous oxide with 45·6 per cent. silica. These pure end members of the series are, however, not known as minerals. The colour of these minerals depends on the amount of iron that enters into their composition: enstatite is white, yellowish, or greenish (plate 65, fig. 1), bronzite green or brown, and hypersthene is dark green or blackish-brown (plate 65, fig. 2). In addition to these body-colours, bronzite exhibits a metallic bronze-like lustre, and hypersthene a metallic coppery sheen. These metallic reflections are caused by numerous thin scales of a dark coloured mineral (supposed to be ilmenite) embedded in the material and arranged parallel to certain crystallographic planes (text-fig. 229). As the mineral readily breaks along these directions, the metallic reflection is especially well shown on these surfaces of separation. In addition, there are also two directions of true cleavage parallel to the faces of the vertical prism, which are inclined to one another at nearly a right angle (88o).

The specific gravity of these minerals varies, like the colour, with the amount of iron present; ranging from 3·1 in enstatite to 3·5 in hypersthene. The hardness is between 5 and 6 for all. When weathered they become softer, and pass into serpentine, talc, or steatite. Fig. 1 of plate 65, for instance, represents a crystal of enstatite which has been completely changed to steatite. Material that exhibits a metallic sheen does not lose this when weathered: for example, the bastite or schiller-spar of Baste in Radauthal, Harz, is a bronzite which has been altered to serpentine.

Crystals of these rhombic pyroxenes are of quite rare occurrence. The largest are those of enstatite from Kjörrestad in the parish of Bamle, Norway, where rough crystals exceeding 40 cm. in length have been found. That represented in plate 65, fig. 1, is bounded by the large ortho-pinacoid (to the front), the vertical prism (the faces at the sides), and a rounded basal plane. More usually, these minerals occur in irregular grains as the constituents of igneous rocks, namely: enstatite in andesite, bronzite with olivine in the basic segregations in basalt, and hypersthene in gabbro.

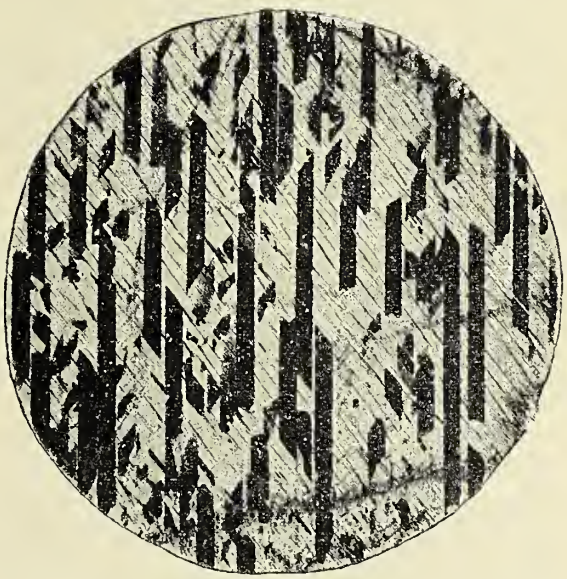

Fig. 229.

Micro-section of Hypersthene with regularly arranged enclosures of a dark mineral.

In thin sections of these rocks the grains of enstatite, etc., show fine cleavage cracks (running diagonally in fig. 229). Dichroism is scarcely noticeable in enstatite, but is stronger in the more ferriferous varieties. The refraction is strong, the mean index for enstatite being 1·669 and for hypersthene 1·702; the birefringence is weak.

Enstatite in its purest form is that found in some meteoric stones; in igneous rocks it is of comparatively rare occurrence. Clear material of a rich green colour and suitable for cutting as gems is found in the "blue ground" of the South African diamond mines. Bronzite is found as large grains at Kupferberg in Bavaria, Kraubat in Styria, and Ultenthal in Tyrol; and as small grains in olivine nodules in the basalts of the Vogelsberg, the Eifel, and many other places. Hypersthene is widely distributed as a constituent of andesite in Transylvania, Auvergne, Nevada, the Andes, etc. Large masses of hypersthene with a fine metallic reflection are found, together with the beautifully coloured labradorite (p. 297), on the island of St. Paul off the coast of Labrador (plate 65, fig. 2). For ornamental purposes this material is cut and polished with a slightly convex surface.

Diopside. In this member of the pyroxene group the magnesium-iron silicate of the enstatite series is combined with an equal molecular amount of calcium silicate, so that the formula becomes $(Mg, Fe)SiO_3 + CaSiO_3$ or $Ca(Mg, Fe)Si_2O_6$. With an increasing amount of iron oxide, isomorphously replacing magnesia, there is a corresponding increase in the depth of colour and in the specific gravity. Typical diopside is transparent and of a pale or darker green colour (plate 65, fig. 4); whilst *hedenbergite*, the member at the iron-rich end of the series, is black and opaque. Sometimes the colour varies in one and the same crystal, one end being pale green or almost colourless and the other end dark leek-green. Alumina is absent or present in only small amount. As an example of the percentage composition, we may quote the following analysis of colourless diopside

from the Ala valley in Piedmont: silica (SiO_2) 54·74, magnesia (MgO) 17·02, ferrous oxide (FeO) 2·91, lime (CaO) 26·03 per cent.

Crystals of diopside are prismatic in habit, with usually a large development of the ortho-pinacoid and the clino-pinacoid, which together give a square prism. This square prism has its edges replaced by narrow faces of the unit vertical prism ∞P, and it is terminated by pyramid and dome faces. On the large crystal in fig. 4, plate 65, the large faces of the clino- and ortho-pinacoids are set vertically, and the edges between them are truncated by the unit vertical prism (seen as a narrow face to the front); and the large face at the top is a pyramid face. The faces of the unit vertical prism are inclined to one another at an angle of 87° 10′, and parallel to them there are perfect cleavages. The hardness is $5^1/_2$—6, and the specific gravity 3·2—3·3.

The typical diopside, such as we have just described, occurs as attached crystals, together with crystals of hessonite and chlorite, in veins in serpentine in the Ala valley in Piedmont (plate 65, fig. 4), and also in the Achmatovsk mines at Zlatoust in the Urals (plate 65, fig. 7); and, at the latter locality, together with garnet, chlorite, and titanite (plate 40, fig. 10).

This typical alumina-free diopside passes by insensible gradations into common aluminous augite, and it is not always easy to decide from the composition whether any particular crystal is to be regarded as diopside or as augite. For this reason the intermediate members have been described under several special names (sahlite, baikalite, fassaite, pyrgom, etc.); but here we shall consider them together under the collective name pyroxene and apart from the typical rock-forming augite. A few of such intermediate members of the series are represented in plate 65, figs. 5, 6, and 8. The dark green, almost black crystals in fig. 5 show (e.g. the crystal set vertically in the centre) the two large pinacoids, a very narrow vertical prism not more than a mere line on the front edge, and the dull basal plane dusted over with chlorite. Their dark colour indicates the presence of much iron, as proved by the following analysis: silica (SiO_2) 51·0, magnesia (MgO) 5·9, ferrous oxide (FeO) 17·3, ferric oxide (Fe_2O_3) 1·0, alumina (Al_2O_3) 1·0, and lime (CaO) 22·4 per cent. This specimen is from the iron mines at Nordmark, near Philipstad in Wermland, Sweden.

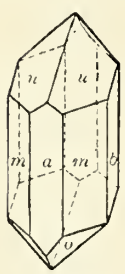

Fig. 230. Crystal of monoclinic Pyroxene.

In fig. 8 the faces of the unit vertical prism are much wider, otherwise the form is the same as in the crystal of diopside in fig. 4. These crystals, which are tilted forward to show the faces at the top, are explained by the accompanying text-fig. 230: m is the unit vertical prism ∞P, a the ortho-pinacoid $\infty P \bar{\infty}$, b the clino-pinacoid $\infty P \breve{\infty}$, and u and o are pyramids. These crystals are from North Burgess in Lanark Co., Ontario, Canada, and may be regarded as diopside.

The crystal in fig. 6 is again of the same form, but here the faces of the unit vertical prism are still more largely developed. The white matrix is calcite, and the pyroxene has here been formed in the crystalline limestone as a result of metamorphism at the contact with an intruded mass of igneous rock. The locality of this specimen is Pitcairn, St. Lawrence Co., in the State of New York. A similar green pyroxene, called fassaite, occurs as a contact mineral in the Fassa valley in southern Tyrol.

Augite. This is the most abundant of the members of the pyroxene group, and one of the most important of the rock-forming minerals. Like the majority of the rock-forming minerals, it is unattractive in appearance; its crystals are brownish-black and opaque (plate 65, figs. 9—11) — never beautifully coloured, clear, or of large size.

The simple crystals, as well as the twins, possess a very characteristic form, and it is easy to recognize that they have only one plane of symmetry and are consequently monoclinic. With the unit vertical prism (*m* in text-fig. 231) is combined the ortho-pinacoid *a* and the clino-pinacoid *b*, the two faces of the latter being parallel to the plane of symmetry. The angles between the faces of the unit vertical prism are 87° and 93°, so that the prism-zone of eight faces is a nearly regular octagonal prism. The ends of this prism are closed by two obliquely-placed pyramid faces *s*, which are sometimes briefly spoken of as an augite pair. Sometimes there is in addition a basal plane. Text-fig. 231 corresponds exactly with the crystal represented in plate 65, fig. 9. In the twinned crystals (fig. 232) the two individuals have in common a face of the ortho-pinacoid. If we consider the simple crystal (fig. 231) to be cut into two equal halves by a plane parallel to *a*, and then rotate the front half through 180° about a normal to this plane, we shall obtain the twinned crystal (fig. 232). The characteristic feature of such twins of augite is the presence of a re-entrant angle at one end (plate 65, fig. 10), and of four faces with salient angles at the opposite end (plate 65, fig. 11). Crystals of augite are found embedded in certain rocks (lava, basalt, etc.), and they are bounded by faces on all sides. They are usually of small size, the crystal represented in fig. 10 being an average size, whilst those in figs. 9 and 10 are above the average.

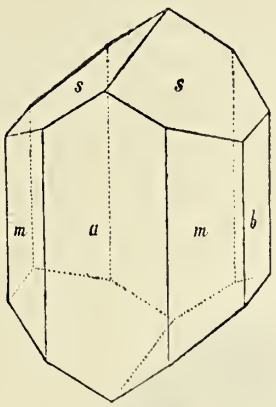

Fig. 231.
Simple crystal of Augite.

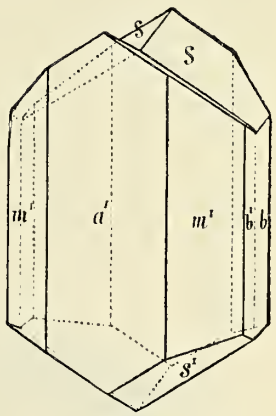

Fig. 232.
Twinned crystal of Augite.

The specific gravity is 3·3—3·4, and the hardness 5—6. There are good, though scarcely perfect, cleavages parallel to the prism faces, and the fracture is conchoidal rather than even. The other characters can only be recognized in thin sections, since the crystals in bulk are quite opaque.

In thin sections the mineral is transparent and of a light brown or violet-brown colour. The crystals show an eight-sided outline in sections perpendicular to the prism, and a six-sided or rhomb-shaped outline in sections parallel to the prism edges. When there are only grains, and not crystals in the rock, the outlines are of course irregular. In these sections the cleavage cracks parallel to the prism faces are always prominently developed, and when the section in perpendicular to the prism these cross at an angle of nearly 90° (plate 67, fig. 1). The darkness of these cleavage cracks and of the outlines indicate that the refraction of the mineral is high ($n = 1{\cdot}72$). The pleochroism is always feeble: when the section is rotated over the lower nicol prism scarcely any change in colour is noticeable.

Between crossed nicols brilliant polarization colours are seen, indicating that the double refraction is strong. Turning a rhomb-shaped section (i. e. one parallel to the plane of symmetry of the crystal) into the position of extinction we see that the angle of extinction (p. 61), as measured to the prism edge, is very oblique, exceeding, in fact, 40°. On account of this oblique extinction, twinned crystals are always readily recognized when examined in polarized light, even if they show no re-entrant angle at their outlines. When one portion of the twin is turned into the position of extinction the other portion is bright (text-fig. 233).

In some instances a twin individual may be present as a very thin lamella inlaid in an otherwise simple crystal. Without examination under the microscope such a twin would be entirely overlooked. As will be mentioned farther on under hornblende, we sometimes see a regular intergrowth of augite with hornblende (plate 67, fig. 3).

The chemical composition of augite is complicated by the presence of aluminia and ferric oxide, and sometimes also of titanic acid and manganous oxide, in addition to the constituents of diopside, and further these constituents may be present in varying amounts. The following figures give the results of analyses of augite from: I, Härtlingen in Westerwald, Hesse-Nassau, and II, Limburg in the Kaiserstuhl, Baden.

	SiO_2.	TiO_2.	Al_2O_3.	Fe_2O_3.	FeO.	MnO.	CaO.	MgO.
I.	47·52	--	8·13	5·83	7·77	0·40	18·25	12·76
II.	44·15	4·57	6·90	6·02	3·49	—	22·79	12·26.

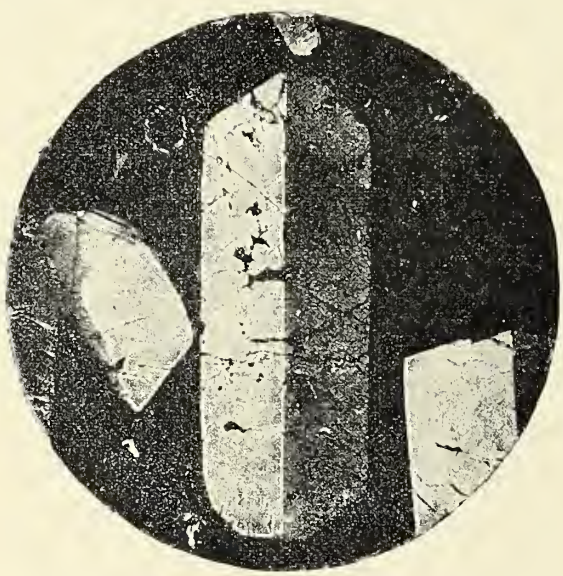

Fig. 233.
Twinned crystal of Augite in polarized light.

Some augites also contain chromic oxide, and others soda, etc. The general chemical formula which expresses these wide ranges in composition has been given above (p. 312). Acids, even hydrofluoric, have scarcely any action on augite, yet in nature it becomes altered by weathering, giving rise especially to chlorite.

Augite with the characters here described occurs as an essential constituent of igneous rocks, such as basalt, diabase, and melaphyre, and their associated tuffs. The loose crystals are mostly collected from the tuffs and ashes of active volcanoes. A few of the many localities are: Vesuvius and Etna; the ancient volcanoes of the Laacher See, Westerwald, Vogelsberg, Rhön, and Kaiserstuhl Mountains in Germany; as well-formed isolated crystals in the basalt-tuffs of the Midland Mountains of Bohemia, e. g. at Schima, Boreslau, and Wolfsberg, near Czernoschin (plate 65, figs. 9 and 11).

Diallage. This member of the pyroxene group is practically the same as augite in its chemical composition, but it differs from this in its structure and occurrence. It is never found as crystals, but only as irregular masses. These possess a characteristic foliated or laminated structure, parallel to which the mineral readily breaks. On these surfaces the lustre is pearly or metallic with a peculiar sheen. This platy separation is very similar to that met with in the rhombic pyroxenes, and, indeed, with the unaided eye it is not always possible to distinguish between diallage and bronzite. In thin sections under the polarizing microscope they are once distinguished, since diallage gives the oblique extinction of augite, whilst bronzite gives straight extinction.

The colour is brown, grey, or greenish, and very often patchy in its distribution (plate 65, fig. 12) due to the partial alteration of the material to serpentine or chlorite. In its other characters diallage is very similar to augite. It occurs as an essential constituent of gabbro, a rock consisting also of labradorite and often olivine. A few localities

are: Volpersdorf in Silesia, Radauthal in the Harz, Ultenthal in Tyrol, Prato near Florence, the Lizard district in Cornwall, Lendalfoot in Ayrshire, and the Island of Skye.

Spodumene. To French mineralogists this mineral is known as triphane. From the members of the pyroxene group so far mentioned it differs very widely in chemical composition, for it contains no calcium, magnesium, or iron, or these in only quite small amounts. It is a silicate of aluminium and the rare alkali metal lithium. A crystal from Huntington in Massachusetts, similar to the one represented in plate 65, fig. 3, gave on analysis: —

SiO_2.	Al_2O_3.	FeO.	CaO.	MgO.	Li_2O.	K_2O.	Na_2O.	Total.
63·79	27·03	0·39	0·73	0·21	7·04	0·12	1·10	100·41.

That the mineral contains little or no iron is obvious from its very pale colour. The presence of lithium is readily demonstrated by the characteristic deep crimson colour which a fragment of the mineral imparts to the flame of a Bunsen-burner. Although differing from augite so markedly in composition, yet it has the same type of meta-silicate formula, namely $LiAlSi_2O_6$, and there is further a close similarity in the crystalline form. The crystals are monoclinic, and the faces of the unit vertical prism are inclined to one another at an angle of 87° (as in augite); the ortho-pinacoid is developed as a wide face deeply grooved vertically (the large face to the front in plate 65, fig. 3); and at the end of the crystal is a pair of obliquely-placed faces — the so-called augite pair. Parallel to the faces of the unit vertical prism there are, as in augite, perfect cleavages. Foliated and columnar masses of spodumene are also found.

The colour of the mineral is usually a pale greyish-white, rose-red, yellowish-green, or violet. Clear crystals of a magnificent emerald-green colour, this colour being due to the presence of a trace of chromic oxide, have received the name *hiddenite* (or, erroneously, lithia-emerald); whilst transparent crystals of a beautiful lilac or violet shade of colour are known as *kunzite*. These green and lilac-coloured crystals are strongly pleochroic, and when they are employed as gems it is important that they should be cut in a certain direction to show the colour to the best advantage. The specific gravity of 3·1—3·2 affords a ready means of distinguishing between the green hiddenite variety and emerald.

Spodumene is on the whole a rare mineral, and the crystals are almost exclusively of American origin. It is found, together with mica, beryl, and tourmaline in a quartz vein traversing mica-schist at Huntington (formerly called Norwich) in Massachusetts (plate 65, fig. 3); and with tourmaline and beryl at Goshen in Massachusetts. Enormous crystals, reaching a length of 42 feet and with a cross-section of 3 by 6 feet, have been found in the Etta tin mine at Harney Peak in the Black Hills of South Dakota. The hiddenite variety is found together with emerald at Stony Point in Alexander Co., North Carolina; and transparent, yellowish-green crystals and fragments come from Minas Geraes, Brazil. The kunzite variety is found as clear crystals, sometimes several inches in length, in pegmatite-veins at Pala and elsewhere in San Diego Co., California; and quite recently in the pegmatites near Antsirabe in Madagascar.

The yellowish-green spodumene from Brazil, the emerald-green hiddenite, and the violet kunzite are cut as gem-stones. Of these, hiddenite is especially rare and correspondingly valuable. The large crystals of cloudy spodumene when they occur in sufficient quantity, as in the Black Hills in South Dakota, have been collected for the preparation of lithium salts.

Another mineral of the pyroxene group, and one very closely related to spodumene, is *jadeite*, which will be further mentioned under nephrite when we come to the amphibole group.

Acmite. Crystals of acmite differ considerably in their general form from crystals of augite, and at first sight they would appear to belong to the rhombic series of pyroxenes, rather than to the monoclinic series. Nevertheless, they are in reality monoclinic and their form is essentially the same as that of augite, since the angles between corresponding faces are very nearly the same. In plate 65, figs. 13 and 14, the wide face to the front belongs to the ortho-pinacoid, and the narrow faces on either side are those of the unit vertical prism, the angles between which are 87°, as in augite. The marked difference in appearance from augite is due to the presence of steeply inclined terminal faces, which belong to the pyramid with the Naumannian symbol 6 *P*. These crystals are twinned on the ortho-pinacoid (like the crystal of augite in fig. 11 of the same plate), and for this reason they are terminated by four of the steep pyramid faces equally inclined to the vertical axis, and it is this that produces the apparent rhombic aspect of the crystals. The re-entrant angles between the pyramid faces are not often to be seen, since the crystals are usually broken at this end.

Crystals of the pointed habit just described were named *acmite* (from ἀκμή, a point) by F. Stromeyer in 1821. Later, in 1835, J. Esmark described crystals with obtuse terminations, more like those of ordinary augite, to which he gave the name *aegirite*, after Aegir, a Scandinavian sea-god. The identity of acmite and aegirite was subsequently proved, and unfortunately it is now often customary to adopt the more recent name aegirite for the species rather than the earlier name acmite. It will be seen from the pictures that the obtusely terminated crystal of aegirite (plate 65, fig. 15) is of a blackish-green colour, whilst the acutely terminated crystals of acmite (figs. 13 and 14) are dark brown. These differences are, however, of no real importance, and in all their essential characters the two varieties are identical.

Crystals of acmite (including also aegirite) cleave parallel to the faces of the unit vertical prism, the angles between two cleavage surfaces being 87°. They have a specific gravity of 3·5, and a hardness of 6. In these characters the mineral shows a close relation to common augite. Before the blowpipe it fuses readily, colouring the flame bright yellow and yielding a black, magnetic bead. These reactions indicate respectively the presence of sodium and iron, which are in combination as a silicate with the formula $NaFeSi_2O_6$.

Acmite occurs as long crystals embedded in white quartz (fig. 14) which forms a vein in granite at Eker in Norway. The crystals are often fractured with displacement of the several portions, these being cemented together again by a later growth of quartz and acmite. The aegirite variety occurs as a constituent of nepheline-syenite; and in veins in rocks of this kind it is sometimes found as crystals a foot in length and the thickness of a man's arm. Such crystals are found on the Langesund-fjord in Norway, at Magnet Cove in Arkansas, and at Kangerdluarsuk in Greenland. As a rock constituent it is found in the Kola Peninsula in Finland, the Serra de Tingua in Brazil, and elsewhere.

Many rock-forming augites contain a small percentage of sodium, the presence of which may be ascribed to an intermixture of acmite molecules with the augite molecules. Such intermediate members of the pyroxene group, consisting of an isomorphous mixture of augite and acmite are known as aegirite-augite. They are met with, for example, in the nosean-phonolite of the Laacher See district.

Wollastonite. This mineral receives its name from the English chemist and mineralogist William Hyde Wollaston (1766—1828). Distinctly developed crystals are of rare occurrence and they are mostly only of small size. They are monoclinic with usually a tabular habit, hence the popular name 'tabular spar' for this species. Occasionally delicate tree-like forms of growth are met with, as already represented in plate 2, fig. 5. A more characteristic form of the mineral is as white or grey, platy masses (plate 65, fig. 16) which

exhibit a pearly lustre, or as irregular and radially-fibrous masses with a silky lustre. Such material is almost invariably found in granular crystalline limestone, and usually in association with garnet and idocrase. All these minerals are of contact-metamorphic origin, having been formed in an impure limestone by the baking action of an eruptive rock-mass (granite, syenite, or diorite).

Wollastonite is composed of lime and silica in equal molecular proportions, the formula being $CaSiO_3$. The combination of the lime of the limestone with the silica present as impurities in the same has been effected through the agency of heat and hot solutions given off from the intruded igneous rock. This calcium silicate is also present in diopside, but here it forms a double salt with magnesium-iron silicate: in wollastonite is occurs alone. Wollastonite is decomposed by hydrochloric acid with the separation of gelatinous silica; the lime passes into solution, and this solution will impart to the Bunsen-flame a reddish-yellow coloration characteristic of calcium. By this reaction, depending on the ready decomposition of the mineral, wollastonite can be distinguished from all the other members of the pyroxene group.

Massive, fibrous, and platy wollastonite is found in crystalline limestone at Auerbach in Hesse (plate 65, fig. 16), and at Cziklova in Hungary. Dendritic aggregates occur in crevices in a black limestone at Berggiesshübel in Saxony. Blade-like crystals are found in the ejected blocks of Monte Somma, Vesuvius. Recently, well-formed crystals of considerable size have been met with in the Santa Fé mine, in the state of Chiapas, Mexico.

Amphibole Group.

Between the minerals of the pyroxene group, which have been described in the preceding pages, and those of the amphibole group there exist several very close relations; and with certain limitations they might be considered as forming together one great group. Their chemical constituents are the same, although in most cases these are combined together in different proportions in the two groups. This is best shown in the members consisting of magnesium silicate and calcium silicate. In the pyroxene group we have diopside in which magnesium silicate and calcium silicate are combined in the molecular proportion of 1 : 1; whilst in the corresponding member of the amphibole group, namely in tremolite, the ratio is 3 : 1. The simplest formula which expresses the composition of tremolite is therefore $3\,MgSiO_3 . CaSiO_3$ or $Mg_3CaSi_4O_{12}$. In order to being out this relation in the formula of the other members of the group, the amphiboles must be considered as salts of the acid $H_8Si_4O_{12}$. The formula of the simple magnesium silicate would then be $Mg_4Si_4O_{12}$, which only differs from the formula $MgSiO_3$ in being multiplied by four, the ratio of magnesia to silica as found by quantitative chemical analysis being the same for both. This formula merely expresses that the molecule of a member of the amphibole group is larger than the molecule of the corresponding member of the pyroxene group: so that we here have a special kind of dimorphism.

The simple magnesium silicate $Mg_4Si_4O_{12}$ may be intermixed with more or less ferrous iron silicate (anthophyllite), or it may be combined with calcium silicate (tremolite and actinolite). In other members of the group alumina may also be present (hornblende); whilst in others soda may take the place of lime, and ferric oxide the place of alumina. The analogy with the minerals of the pyroxene group is complete, with the exception that in the amphibole group there is no representative rich in lithia.

As in the pyroxene group, so also here the chemically simpler members crystallize in the rhombic system, the others in the monoclinic, whilst the triclinic members are of little importance. All of them possess distinct cleavages parallel to the faces of the vertical prism; but, whilst in the pyroxenes the angle between these cleavages is 87°, in the amphiboles it is 56° (or the supplement of this, 124°). The specific gravity of all the amphiboles lies between 3·0 and 3·2, being lower than for the pyroxenes. When amphibole is fused it consolidates not as amphibole, but as pyroxene with the higher specific gravity.

We can now give the following summary of the minerals of the amphibole group.

Anthophyllite, $(Mg, Fe)_4Si_4O_{12}$	Rhombic.
Tremolite and Actinolite, $(Mg, Fe)_3CaSi_4O_{12}$	Monoclinic.
Hornblende, $(Mg, Fe)_3CaSi_4O_{12} . CaMg_2Al_2Si_3O_{12} . Na_2Al_2Si_4O_{12}$	Monoclinic.
Glaucophane, $Na_2Al_2Si_4O_{12}$.	Monoclinic.
Riebeckite, $Na_2Fe_2Si_4O_{12}$	Monoclinic.

Of these minerals *anthophyllite* need be only briefly mentioned, since it is of rare occurrence. It forms brown, fibrous aggregates, with a specific gravity of 3·2. Its formula expressed in the most simple form is the same as that of enstatite (p. 312), namely $MgSiO_3$, and it is here that the dimorphic relation is most clearly shown.

Another member also of minor importance is *glaucophane*. This occurs but rarely as crystals, and it usually forms granular or fibrous aggregates of a dark blue colour. Its strong pleochroism, easy fusibility, and perfect prismatic cleavage are characteristic features. It is of interest as a constituent of certain schistose rocks (glaucophane-schists) met with in a few widely separated districts, namely, the Island of Syra, Zermatt in Switzerland, in Brittany, and on Shikoku in Japan.

The remaining members of the amphibole group, together with some of their more important varieties, will now be described in detail.

Tremolite and **Actinolite.** The first of these two minerals contains little or no iron, and it is consequently white or colourless. Actinolite, on the other hand, contains much more iron, and it is dark green in colour (plate 66, fig. 1). Both of them occur as blades or slender prisms embedded in chlorite-schist or talc-schist, granular limestone or dolomite, and in other crystalline rocks. The crystals are bounded by the faces of the vertical prism with sometimes the clino-pinacoid, but without terminal faces. They may occur singly in the rock, but more frequently they are closely aggregated to form radially disposed masses of needles, or the aggregation may be confused and irregular.

The specific gravity varies from 3·0 to 3·2, according to the amount of iron present, and the hardness is $5\frac{1}{2}$—6.

Tremolite and actinolite are characteristically minerals of crystalline schistose rocks and as such are met with in Alpine regions. They are never found as attached crystals on the walls of crevices, the reason for this apparently being that pressure is an agent necessary for their formation. Tremolite receives its name from the Val Tremola on the southern side of St. Gotthard, and the best specimens come from the white crystalline dolomite of Campo longo in the same district. It contains: SiO_2, 58·05; MgO, 27·18; CaO, 13·91; H_2O, 0·34 per cent. Actinolite is of much wider distribution and is found at many places in the Swiss and Tyrolese Alps. Well-known localities are: on the Greiner in the Zillerthal and the Pfitsch valley in Tyrol; the St. Gotthard district, and Pommat in Val Formazza (plate 66, fig. 1) in Switzerland. The actinolite of the Zillerthal contains 6—25 per cent. of iron (ferrous) oxide with correspondingly less magnesia. As rock-forming constituents, both minerals sometimes occur in abundance as tremolite-schist and actinolite-schist.

A compact and microscopically fibrous variety of actinolite is the well-known *nephrite*, which by reason of its special interest will be treated, together with jadeite, in a later section.

An emerald-green variety of actinolite known as *smaragdite* forms, together with grass-green pyroxene (omphacite) and brown garnet, a prettily coloured crystalline rock called eclogite. As a constituent of this rock, smaragdite occurs in the Fichtel Mountains of Bavaria and at Sau Alp in Carinthia (plate 66, fig. 7).

Asbestos. The name asbestos, from the Greek and meaning "unquenched", is applied to minerals which possess a finely fibrous texture and flexibility, so that they can be spun like thread, and which are at the same time incombustible. As shown by their chemical composition such minerals may belong either to tremolite and actinolite (asbestos proper) or to serpentine (serpentine-asbestos), or less commonly to crocidolite (p. 323).

The asbestos proper, or *amphibole-asbestos*, forms white or greenish, fibrous masses from which the single fibres may be easily separated (plate 66, fig. 9). The fibres are sometimes brittle, but frequently they are so pliable and tough that they can be spun and woven. In the variety known as *amianthus* the fibres are so extremly fine that the material has a silky lustre. In some other varieties the fine fibres are matted together to form a felt, such material being variously called, as suggested by its appearance, *mountain-leather* and *mountain-cork*. Although asbestos in larger masses is resistant to high temperatures, yet the fine fibres taken separately can be fused before the blowpipe. That asbestos belongs to the amphibole group is proved by quantitative chemical analysis; for example, a specimen from the Zillerthal, Tyrol, gave: SiO_2, 57·20; CaO, 13·39; MgO, 22·85; FeO, 4·37; H_2O, 2·43. This corresponds closely with the analysis of tremolite quoted above, except that a small proportion of the magnesia is replaced by ferrous iron. The small amount of water often present in asbestos is probably due to incipient alteration.

Asbestos occurs embedded in talc-schist, chlorite-schist, serpentine, or crystalline limestone, and is of wide distribution, but it is not many occurrences that are of economic value. A few of the better known localities are: the Gamskarkogel near Gastein in Austria, where the material occurs in workable quantities; the Knappenwand in Untersulzbachthal, Salzburg, with crystals of epidote (plate 50, fig. 5); the Zillerthal and Pfitsch valley in Tyrol; rich deposits of good quality asbestos are worked in the neighbourhood of Sondrio in Valtellina and in the province of Turin.

The supply of amphibole-asbestos comes mainly from the north of Italy, where the output in the year 1901 amounted to 2000 tons. Of far greater commercial importance than the Italian asbestos is, however, the Canadian asbestos which is a serpentine-asbestos: of the latter the production in 1908 amounted to 65,534 short tons (of 2000 lbs.) valued at about £ 510,000.

The applications of asbestos depend on its incombustibility, its finely fibrous texture, and its low degree of conductivity for heat. It is used as a packing in the pistons and stuffing-boxes of steam-engines and the joints of steam pipes; as an insulating material for covering steam and hot-water pipes; as a filtering material; lamp wicks; loose soles in boots and shoes; imitation snow for theatres and christmas trees; the upper portion of incandescent gas-light mantles. Further, as a fire-proof material for the construction of theatre curtains, boards, and walls. Asbestos fibre coated with platinum (platinized asbestos) is employed in the manufacture of sulphuric acid by the contact process. For spinning and weaving, in the manufacture of asbestos twin and cloth, serpentine-asbestos is on the whole more suitable than amphibole-asbestos, since the fibres of the former are finer, softer, and more flexible.

The practical uses of asbestos date back to very early times. The golden lamp of Minerva at Athens had a wick of asbestos; and the ancient Romans cremated corpses in asbestos shrouds, so that the ashes were kept separate from the ashes of the fire. Karl V, emperor of Germany, had a table-cloth made of asbestos, which, to the amusement of his guests, was cleansed after a meal by being thrown on the fire.

Hornblende. Of all the minerals of amphibole group hornblende shows the best crystals. These belong to the monoclinic system, and in their external shape they present a certain resemblance to hexagonal forms. On this account, hornblende was formerly confused with tourmaline, and the old name schorl was applied indiscriminately to any black crystals of prismatic habit. It was not until the end of the eighteenth century that the two species were distinguished, the name schorl being reserved for tourmaline, while the name hornblende was applied by the German mineralogist Werner to the present mineral. The French mineralogist Haüy gave to it the name amphibole, which signifies that it had been mistaken for other minerals. At the present day the name amphibole is usually applied to the whole group, and hornblende to one member of the group.

The simple crystals (plate 66, fig. 2) are bounded by a rhombic prism parallel to the faces of which there are perfect cleavages enclosing an angle of 124° 10′ (or the supplement 55° 50′): this prism is taken as the unit vertical prism ∞P (*p* in text-fig. 234). The acute edges of this prism are truncated by the pair of parallel faces of the clino-pinacoid (*b*) parallel to the single plane of symmetry of the crystal. At the end of the crystal are three planes; the one (*c*) which is perpendicular to the plane of symmetry being chosen as the basal plane 0 *P*, and the other two (*o*) belong to the pyramid *P*. The angle between an adjacent pair of pyramid faces is 148° 28′, while each of them are inclined at 145° 35′ to the basal plane. This difference of angle is too slight to be detected by the eye without the help of a goniometer. Again the combination of the rhombic prism with the clino-pinacoid produces a six-sided prism with angles of 124° 10′ and 117° 55′, approximating in each case to 120°. The crystal thus presents the appearance of a hexagonal prism terminated by a rhombohedron, as in a crystal of tourmaline (compare plate 48, fig. 1). The fact that hornblende crystals cannot be rhombohedral is, however, at once seen from the cleavages, which are parallel to only four and not all six of the faces. Hornblende crystals are commonly of a short prismatic habit, as in plate 66, fig. 2, but usually they are smaller than the one here represented. Longer prisms, as in fig. 5, are rarely seen. On the black crystals in fig. 6 the only faces present are those of the unit vertical prism and the basal pinacoid: the clino-pinacoid is absent and in consequence the acute edges of the unit prism are developed.

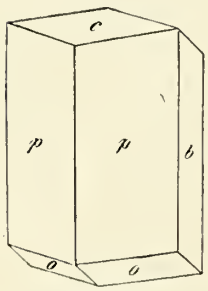

Fig. 234.
Crystal of Hornblende.

Twinned crystals of hornblende are of frequent occurrence. The two individuals of a twin are grown together on a face of the ortho-pinacoid, a face which if developed on the crystal would truncate the front obtuse edge of the prism. The two portions are symmetrical with respect to one another across this plane. Such twins are remarkable in showing no re-entrant angles. At one end there are four pyramid planes (plate 66, fig. 3), and at the other end two basal planes (fig. 4) in juxtaposition. The hornblende crystal now simulates, not a rhombohedral crystal, but a hemimorphic rhombic crystal.

Hornblende is an easy mineral to recognise in thin sections under the microscope. In cross-sections it shows a six-sided outline (plate 67, fig. 2) and in longitudinal sections

usually a four-sided outline (plate 67, fig. 4)*): in the former the straight cracks due to cleavage intersect at an angle of about 120°, while in the latter they are parallel to the vertical axis. The colour of the mineral seen in the thin section is brown or green, and the strong dichroism is a very characteristic feature. As the section is rotated with respect to one of the nicol prisms, the colour changes from pale yellow to dark brown or from yellowish-green to dark green, for brown and green hornblende respectively. In sections cut parallel to the plane of symmetry the angle of optical extinction is 12—18°. These characters — the form of outline and the angle between the cleavage cracks, the strong dichroism, and the lower angle of extinction — serve to distinguish hornblende from augite (p. 315) when seen in thin sections of rocks.

The two related minerals hornblende and augite sometimes form parallel intergrowths (plate 67, fig. 3), as already mentioned on p. 46. Another relation shown by the two minerals is in the alteration of augite to hornblende. A crystal of augite, while still preserving its external form, may be altered in substance to hornblende. The cross-section of such an altered crystal will show the eight-sided outline of augite, but the cleavage cracks are at approximately 120° as in hornblende. Pseudomorphous crystals of this kind were first detected by Gustav Rose in the hornblende rocks of the Ural Mountains, and they were consequently named *uralite*.

An important difference between hornblende and augite is in their specific gravity, that of hornblende being 3·1 and of augite 3·3.

Green hornblende, known as *common hornblende* is of wide distribution as a constituent of syenite and diorite, and it also constitutes the greater part of the hornblende-schists of the Alps. In these rocks the mineral is present as grains, the fractured surfaces of which present a fibrous appearance due to the perfect prismatic cleavages. Freely developed crystals attached to the surface of the matrix are found in the iron mines of Nordmark near Philipstad in Sweden, and at Arendal in Norway (plate 66, fig. 6); and in the ejected blocks of Monte Somma, Vesuvius.

Brown hornblende, known as *basaltic hornblende* occurs as a constituent of trachyte, hornblende-andesite, and many basalts. In these volcanic rocks it is found as embedded crystals bounded on all sides by crystal-faces. Very frequently the edges and corners of these crystals are rounded, due to the solvent action of the molten lava under conditions of pressure different from those which subsisted when the crystals first grew. Such crystals of hornblende are especially frequent in basalt-tuffs, and being isolated in the loose material they are easily collected. Localities for good crystals are: Härtlingen in the Westerwald, Ortenberg in the Vogelsberg, Liebhards and Pferdskopf in the Rhön Mountains, Roda near Predazzo in southern Tyrol (plate 66, fig. 5), and especially in the Midland Mountains of northern Bohemia (Schima, plate 66, figs. 2—4, and Wolfsberg near Czernoschin).

Crocidolite. The mineral riebeckite mentioned in the list of amphiboles an p. 320 is of rare occurrence, and is found at but few places as a constituent of igneous rocks. Of more importance is its finely fibrous variety known as crocidolite (plate 66, fig. 8). This forms blue masses with a parallel-fibrous structure, and occurs as a filling in crevices, forming slabs of greater or less thickness, in clay-slates and jasper-schists on the banks of the Orange River in South Africa. The fibres run from side to side of the slabs and are closely compacted; but when the material is rubbed the individual fibres easily separate into a loose woolly mass (hence the name crocidolite). This mineral is also known as *blue asbestos*, and to some extent it is mined for commercial purposes. The cohesion of the

*) In the explanation to plate 67 the crystal in fig. 4 is incorrectly described as biotite instead of hornblende.

material has at times been increased by the infiltration of silica which is deposited as quartz between the fibres. This may proceed to such an extent that we have a mass of quartz enclosing fibres of crocidolite, as in the blue quartz ("sapphire-quartz") of Golling in Salzburg and the abundant hawk's-eye of the Orange River. With the weathering and alteration of the crocidolite the ferrous oxide it contains is converted into limonite, which impregnating the quartz imparts to it a golden-yellow colour. The result is the well-known tiger-eye (plate 55, figs. 13 and 14), which has already been described (p. 274) as a variety of quartz.

Tiger-eye is employed as a gem-stone and for fashioning small ornamental objects. The finely fibrous crocidolite is put to the same uses as ordinary asbestos, but being much more easily fusible it is not so good for fire resisting purposes.

Nephrite and Jadeite.

These two minerals are so very similar in external appearance and general character that they have always been confused the one for the other; and it was only when they came to be analysed chemically and the specific gravity determined that they were recognized as belonging to distinct species. They are opaque, extremely compact stones with little, save colour, to attract the eye. Nevertheless, they belong to the most interesting of minerals, and since prehistoric times they have been much used for the fashioning of stone implements, personal ornaments, and carvings of various kinds, while at the present day they are highly prized by the Chinese. Compared with the wide distribution of the worked articles in settlements of the greatest antiquity, the rarity of occurrence of the rough material *in situ* is very striking; and the problem as to the origin of the material has been the subject of much inquiry. As a result of mineralogical together with ethnographical and archaeological investigations this problem has now been solved in its main issue.

These stones are known to the Chinese as *yu* or *yu-chi* (yu-stone), and in Persian as *yeshon*. The latter suggests a connexion with the word jasper, under which term the present minerals have no doubt also been included. The name nephrite, first used in this form by A. G. Werner in 1780, is from the old name *lapis nephriticus* or "kidney-stone", since in ancient times the wearing of the stone was believed to be a remedy for diseases of the kidneys. The name *jade*, which is now very often employed to include both nephrite and jadeite, has the same meaning, being derived from the Spanish *ijada* or *piedra de ijada*. When the two species were distinguished by A. Damour in 1863, he proposed for one of them the name *jadeite*.

Nephrite. As previously mentioned (p. 321) this is a member of the amphibole group of minerals essentially identical with actinolite. It forms compact masses with a greenish-yellow, grey, or rarely white colour, and on its broken surfaces it presents a characteristic splintery fracture. This fracture is represented in plate 66, fig. 10, by the lighter-coloured specks and patches, these being due to small translucent splinters partly loosened from the main mass of the stone. The most striking feature of nephrite is its extraordinary degree of toughness.

Some interesting observations respecting the toughness and hardness of nephrite were made by the brothers Schlagintweit, by whom the specimen represented plate 66 was collected in the Gulbashén quarries, situated on the right bank of the Karakash river in Eastern Turkestan (the earliest known locality for Asiatic nephrite). They caused a

steel chisel loaded with 50 kilograms to fall from a height of 35 centimetres through a tube onto a block of nephrite, with the result that the chisel was broken whilst the stone remained uninjured. They also remark that when the stone is first taken out of the quarry, especially from the deeper portions, it is softer and more readily worked; this being no doubt due to the presence of moisture, which is lost on exposure to the air. Other more severe tests were made by H. Fischer. He placed a large block of nephrite under a steam-hammer, with the result that the anvil, and not the stone, was broken. The remark of Pliny that diamond cannot be broken on an anvil with a blow from a hammer (p. 205) thus applies much more correctly to nephrite than to diamond. The toughness may be overcome and the stone broken by the application of fire: when a heated stone is thrown into cold water it breaks into small fragments. On this depends the ancient method of fire-setting employed in quarrying the material.

The hardness (H. = $5^1/_2$—6), though greater than that of glass, is not high, being considerably less than that of quartz and of all the precious stones. This character is, however, quite distinct from that of toughness. It is on the latter that the durability of the stone depends. And on this account the material has at all times and in all parts of the world found favour as a material for stone implements, weapons, and personal ornaments. These being regarded as talismans and amulets, came in time to have special superstitions and healing virtues attached to them.

The toughness of nephrite is a consequence of a pecularity of the internal structure of the stone. In thin sections under the microscope the material is seen to consist of extremely fine fibres which are closely and confusedly aggregated to form a compact felt-like mass. That the fibres consist of actinolite is proved by their cleavages and low angle of optical extinction. Different specimens show differences in the size of the fibres and they may be intermixed to a greater or less extent with other minerals. The most frequent of these are grains of diopside. These small differences are, however, of importance, since they enable us to determine the probable source of the material. Thus, Arzruni by a microscopical examination of nephrite objects from Swiss lake-dwellings proved that the material differed from the nephrite from Central Asia, Siberia, and New Zealand, so that it had not, as previously assumed, been brought from these remote regions.

A microscopical examination of the material is only possible when a chip can be removed from the specimen, but this would not allowable in the case of worked articles. The best test then available is that afforded by the specific gravity, the object being weighed in air and in water: the value for nephrite lies between the limits 2·95—3·1, whilst jadeite has the higher value 3·32—3·35. Another ready test for the discrimination of these minerals is given by their fusibility and the colour that they impart to the Bunsen-flame: small flakes of jadeite fuse easily in the flame and impart a bright yellow colour, whilst nephrite fuses only with difficulty.

In chemical composition, nephrite is identical with actinolite or tremolite, the amount of iron actually present varying with the depth of colour of the material. An analysis by E. Schütz of nephrite from Shahidulla in Eastern Turkestan gave: silica (SiO_2), 57·69; alumina (Al_2O_3), 1·58; ferrous oxide (FeO), 2·60; lime (CaO), 13·81; magnesia (MgO), 22·55; water (H_2O), 1·75 per cent. (Compare with this the analysis of tremolite given on p. 320.)

Occurrence of nephrite. — Although worked articles of nephrite are found in many parts of the world, it is only at a few places that the rough material has been found *in situ*. Until year 1884 no occurrence in Europe had been discovered; and Heinrich Fischer, the author of the authoritative work "Nephrit und Jadeit" (2nd edition, 1880), had expressed the opinion that the all the material found amongst prehistoric remains

in Europe had been brought from Asia, either along trade routes or with the migration of the early tribes. On the other hand, Andreas Arzruni pointed out that all the objects of nephrite found in the neighbourhood of the Alps, although similar amongst themselves in microscopical character, differed appreciably in this respect from Asiatic nephrite. He consequently believed that the material was not of exotic origin, in spite of the fact that up to that time no Alpine occurrence was known. In the year 1884, however, nephrite was discovered by Hermann Traube *in situ* at Jordansmühl in Silesia. It here forms a band between granulite and serpentine, and is also present as rounded nodules in the serpentine; that occurring in the band being dark green in colour, whilst the nodules are light green. Traube also later recorded the occurrence of nephrite at Reichenstein in Silesia, whilst quite recently (J. Uhlig, 1910) veins of nephrite have been observed in the gabbro-serpentine rocks of the Radauthal in the Harz Mountains. "Henckelius in Mineralogia redivivus" (1759, p. 30) mentions *lapis nephriticus* from the serpentine quarry at Zöblitz, Saxony. It is quite likely that this was only a compact serpentine; but still this early mention, hitherto overlooked, is of interest. The presence of isolated boulders of nephrite in northern Germany (e. g. at Schwemal near Düben in the Leipzig district) in without explanation.

In Asia, the occurrence of nephrite *in situ* was first recorded by the brothers Schlagintweit, who in 1856 and 1857 visited the Konakán and Karalá quarries in the neighbourhood of Gulbashén and Shahidulla-Chodja on the right bank of the Karakash river in Eastern Turkestan. This locality is situated on the northern slopes of the Kuen-Lun Mountains: other occurrences are known on the southern slopes of this range, to the westward in the Pamir region, and to the east in the Chinese province of Kan-su. The occurrences *in situ* are always in the neighbourhood of gneiss and crystalline schists. Boulders and pebbles of nephrite are abundant in the river beds throughout the whole region. In the villages on the northern slopes of the Nan-Shan an extensive trade in nephrite is carried on, the peasants collecting it for sale to Chinese merchants. Large boulders of nephrite are also found in the river beds in government Irkutsk in Siberia. Worked articles as well as the rough material are also met with in Alaska. In New Zealand, nephrite is abundant, being found on the west coast *in situ* and as pebbles in the river beds and on the sea beach. This is the well-known New Zealand greenstone, or *pounamu* of the Maoris.

Jadeite. This is a member of the pyroxene group and is analogous to spodumene in chemical composition (p. 316). As already mentioned, jadeite is strikingly similar in its general appearance to nephrite, though perhaps it is more often of a fine green, sometimes emerald-green, colour, than the latter. Usually, however, it shows just the same yellowish-green, greyish-green, and white colours as does nephrite. Even experts fail to distinguish the two minerals by sight alone. Distinguishing features of importance are the higher specific gravity (3·32—3·35) of jadeite, its much lower degree of fusibility, and the yellow coloration which it imparts to the Bunsen-flame. This characteristic flame-coloration is due to the presence of sodium in the mineral. An analysis by Lemberg of jadeite from Burma gave: silica (SiO_2), 58·95; alumina (Al_2O_3), 25·17; soda (Na_2O), 14·70; lime (CaO), 0·41; magnesia (MgO), 0·47; water (H_2O), 0·30 per cent. The mineral is thus a silicate of aluminium and sodium with the formula $NaAlSi_2O_6$, a formula analogous to that of spodumene but with sodium in place of lithium.

Not only do the specific gravity and chemical composition indicate that jadeite belongs to the pyroxene group, but so also do the microscopical characters. When thin sections of the material are examined under the polarizing microscope, it is seen to possess a granular, rarely fibrous, texture, and the individual grains show the cleavage and wide angle of optical extinction characteristic of the pyroxenes. As a rule the individual par-

ticles are rather larger in jadeite than in nephrite; and some pale coloured jadeites have somewhat the aspect of marble, although of course they are much harder, tougher, and heavier than this.

The jadeite of Upper Burma is perfectly pure, no trace of any another mineral being intermixed with the jadeite grains. In this respect it differs widely from the jadeite of worked objects found in Europe, in which other minerals are sometimes present in considerable amount.

Some jadeites contain iron oxide and are consequently darkly coloured, this being especially the case in the variety *chloromelanite*, so called from its greenish-black colour. This variety is found in Europe only as worked objects, especially axe-heads (plate 66, fig. 11); most of these are found in France, and a few in Switzerland, that represented in the picture being from the lake-dwellings on Lake Neuchâtel. Worked objects are also occasionally found in Mexico, Guatemala, Colombia, New Guinea, and elsewhere. Chloromelanite is said to occur *in situ* in New Guinea.

The hardness and toughness of jadeite are slightly greater than of nephrite. The mineral is put to exactly the same uses as nephrite, as will be described farther on.

Occurrence of jadeite. — In Europe, jadeite is not known with certainty to occur *in situ*; the only rough material so far found consists merely of pebbles which have not been traced to their original bed. All the jadeite which comes into the trade is from Asia, but even of Asiatic occurrences (probably in Tibet and Eastern Turkestan) the only one of which we have any definite particulars is that in Upper Burma. Until comparatively recently this remote region was practically unknown to Europeans. It was examined geologically by F. Noetling in 1892, and more recently by A. W. G. Bleeck in 1907.

The jadeite-mining district of Upper Burma is of limited extent, and is situated in the Kachin Hills, about 120 miles from Mogaung. The material is quarried from the solid rock at the village of Tawmaw; and as pebbles and boulders it is collected from the bed and banks of the river Uru, a tributary of the Chindwin. Although the alluvial deposits have been worked since a remote period, they are not yet exhausted. Deposits of laterite in the valley also contain a few blocks of jadeite; these are iron-stained and of a rich reddish-brown colour, which is much admired by the natives and by the Chinese. The occurrence of the mineral *in situ* at Tawmaw was first known about the year 1880. Here in the midst of the jungle a low isolated hill composed of dark green serpentine projects through the surrounding sandstone. The jadeite forms a thick bed, or perhaps dyke, in this serpentine rock. Hundreds of the natives work in an enormous quarry loosening blocks of the tough intractable stone by the primitive method of fire-setting. The bulk of this jadeite is a snow-white, fine-grained stone resembling marble, in which irregular patches of the beautiful emerald-green material are enclosed. The latter is the more valuable material specially sought for by the Burmese and Chinese. The larger part of the output remains in Burma or is exported into China; only a small amount being sent to Europe.

Applications of nephrite and jadeite. — *Nephrite* was employed in prehistoric times as the material for stone implements and weapons; these are often beautifully finished, and were perhaps used only for ceremonial purposes. The axe-head represented in plate 66, fig. 11 was fixed in the crown of a deer's antler and this mounted on a wooden stick. In Europe, such nephrite implements are found principally in the neighbourhood of the Alps, in Switzerland, southern Baden, and Bavaria. In southern Asia and more especially in the east, nephrite remains to the present day a favourite material for all kinds of ceremonial and ornamental objects, such as amulets, ring-stones, rings, bowls, vases, boxes, cups, sword- and knife-handles. Elaborate designs and groups of men and animals, similar to those cut in agalmatolite, are also carved with infinite patience. Spheres, ovoids, discs,

and cylinders are bored for use as necklets. The cylinders are bored in the direction of their length, and resemble the ancient Assyrian cylinder-seals and the Trojan rolls. In western countries nephrite is coming more and more into favour for ornamental objects. Umbrella- and knife-handles, and even bowls, are now cut at Oberstein in Germany. Owing to the toughness of the material, the working consumes much time, and consequently even these modern reproductions are costly. A number of ancient nephrite objects, artistically

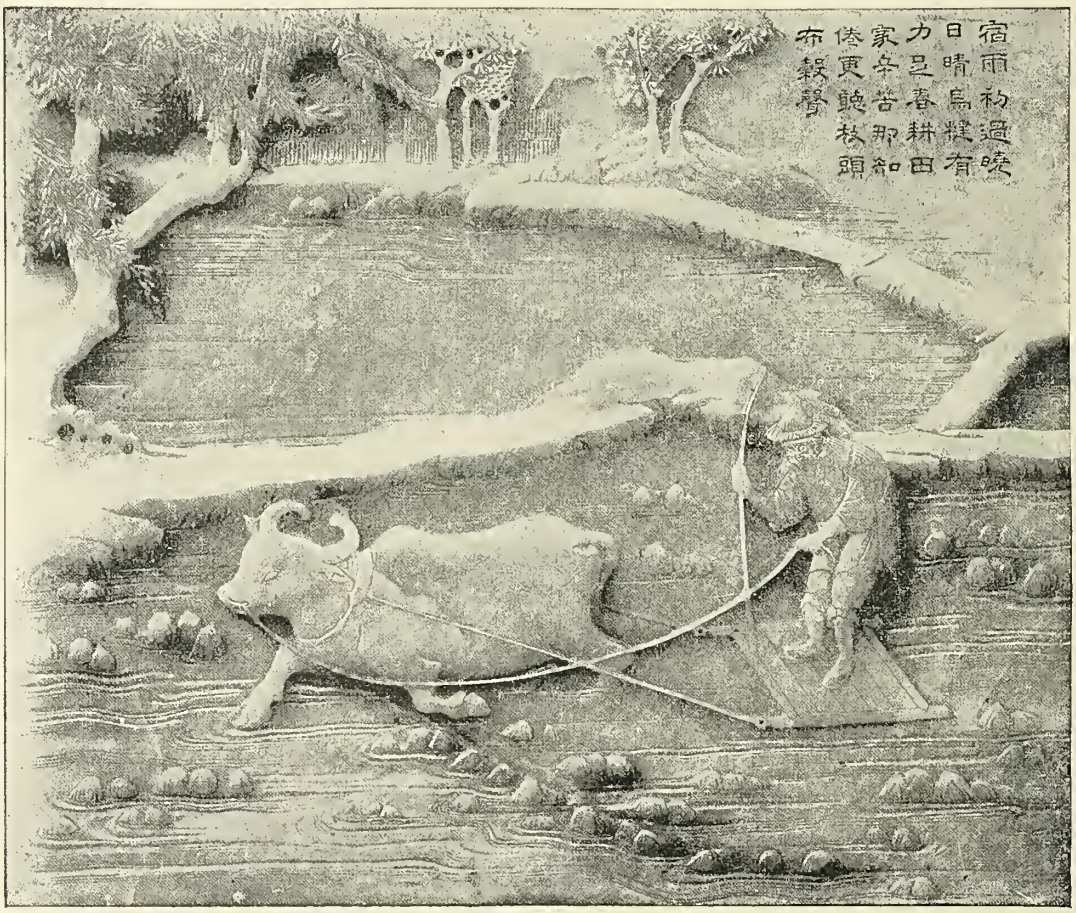

Fig. 235.
Chinese carving in Jadeite.

worked and ornamented with gold and valuable precious stones, are preserved in the Green Vaults at Dresden.

Jadeite is put to practical the same uses as nephrite, only it is less abundant. Worked objects, more especially flat axe-heads, of jadeite are found mostly in the north-west of France, whither they were carried as charms against evil. They were built into the foundations and walls of some of the huts as a protection against lightning. Ancient jadeite objects are also of wide distribution in North, Central, and South America. Some of these have the form of plates and long thin rods, which when struck emit a musical note. The famous Aztec ceremonial axe in the Berlin Museum was brought from Mexico by Alexander von Humboldt.

A valuable example of Chinese carving in jadeite is represented on a reduced scale in the accompanying text-fig. 235: the original measures 25·2 by 21·7 centimetres. The

work is of the finest quality, and we marvel at the skill and patience of the artist. The text-figure suggests a reproduction of a painting rather than a carving executed in a particularly hard and tough stone. In the corner is engraved a verse of Chinese poetry*) in praise of the peasant.

Attention may be here called to the remarkable work entitled "Investigations and Studies in Jade" (New York, 1906), descriptive of the unique collection of the late Heber R. Bishop, which was presented by him to the New York Metropolitan Museum of Art. In two huge and sumptuous volumes nephrite and jadeite are dealt with from every possible point of view, whilst the numerous plates are veritable works of art. An edition of one hundred copies was privately printed and distributed amongst the important libraries of the world.

Mica Group.

The minerals belonging to this group possess a cleavage in one direction so perfect that their material can be readily split into the thinnest sheets. All of us are familiar with the mica windows of oil-stoves and the mica chimneys of incandescent gas-burners. If the metal binding of one of these chimneys be removed we shall see that the mica springs back from its curved cylindrial form into a flat sheet. Thin sheets of mica are thus elastic as well as flexible. Some other minerals, e. g. chlorite, which possess a cleavage like that of mica, are flexible but not elastic: the sheets can be bent, but when released they do not spring back to their original position. With the sheet of mica which we have taken out of the lamp chimney we shall be able to demonstrate the other characters of the mineral.

When the sheet is placed in the polariscope we see, using convergent light, a good optical interference-figure, as represented in plate 4, figs. 3 and 4. With most sheets of mica the two black hyperbolic brushes will be widely separated in the field of view; whilst with other specimens, particularly of brown mica, these brushes are very close together in the centre of the field. We thus see that mica is optically biaxial, and that the optic axial angle may be either large or small. This observation proves that mica must belong to either the rhombic, monoclinic, or triclinic system of crystals. It cannot belong to the hexagonal system as is usually suggested by the external form of the crystals (plate 68, figs. 1—6), since hexagonal crystals give a uniaxial interference-figure (plate 4, fig. 1).

In which of these three systems mica crystallizes is not so easily determined. It has, however, been found that etched figures artificially developed on the cleavage surfaces are symmetrical with respect to only one line (text-fig. 236). There can thus be only one plane of symmetry, and the crystals must therefore be monoclinic. We may take the cleavage direction as the basal plane of the monoclinic crystal. Approximately perpendicular to this are six faces, four of which may be taken as belonging to the unit vertical prism, and the remaining two as the clino-pinacoid parallel to the plane of symmetry (and consequently truly perpendicular to the basal plane). In the crystal shown in plate 68, fig. 2, the two narrow faces to the front are prism faces, and those to the right and left (not visible in the picture) belong to the clino-pinacoid. On very perfectly developed crystals the angle between the prism faces has been measured on the goniometer as 120° 11′. When

*) In the German original a transcription and translation are given of this and compared with a fragment of Haydn's "Seasons".

the prism faces are more largely developed than the clino-pinacoid, the crystal may present a rhombic outline.

If the point of a darning-needle or nail is placed against a sheet of mica and struck a short, smart blow with a hammer, there is developed around the central hole a star of six rays. This is known as a "percussion-figure" and is shown in text-fig. 237 by the continuous lines. Two of these rays are parallel to the clino-pinacoid (*b*), and the four others each parallel to the four prism faces. We can now distinguish between the former and the latter by examining the starred cleavage plate in convergent polarized light. The narrower dark band joining the two eyes of the interference-figure (plate 4, fig. 3) is either perpendicular to or parallel to one pair of rays of the percussion-figure: these rays are then the ones parallel to the clino-pinacoid, that is, parallel to the plane of symmetry. It is thus possible, by means of the percussion-figure and the interference-figure to determine the orientation of any irregularly bounded sheet of mica or of a sheet which has been squared and cut with shears.

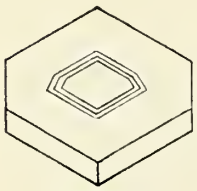

Fig. 236.
Etched figure on cleavage surface of Mica.

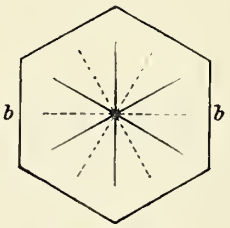

Fig. 237.
Percussion-figure on cleavage surface of Mica.

Those micas in which the narrower dark band of the interference-figure, that is, the plane of the optic axes, is perpendicular to a line of the percussion-figure are known as micas of the *first class*; those in which it is parallel are known as micas of the *second class*. This is more briefly stated by saying that in micas of the first class the plane of the optic axes is perpendicular to the plane of symmetry; whilst in the second class the optic axial plane is parallel to the plane of symmetry.

Another set of cracks is developed on a cleavage sheet of mica by pressing against it a blunt point. This is known as the pressure-figure, and is shown by the dotted lines in text-fig. 237; two of the six rays are perpendicular to the clino-pinacoid *b*, and the others perpendicular to the prism faces. Lines of this kind, probably developed in the mica by earth pressures, are shown in plate 68, fig. 4; the four shorter edges are here the prism edges, and the longer pair those of the clino-pinacoid.

The crystal-faces so far mentioned are those which are perpendicular or approximately perpendicular to the basal plane. In some crystals (plate 68, fig. 1) these faces are replaced by steeply inclined pyramids and dome faces. Although the cleavage surface is so bright and smooth, the other faces of mica crystals are generally dull and rough, and it is only rarely that more than approximate angles can be measured between the faces. Twin intergrowths of mica are of frequent occurrence, but as these are not easily recognized they need not be further mentioned in this place.

According to differences in chemical composition, several varieties of mica may be distinguished. They all contain silica, alumina, alkalis (potash, soda, or lithia), and the constituents of water; in addition, some contain fluorine, magnesia, and iron oxides. It is thus possible to distinguish as chemical varieties: potash-mica, soda-mica, lithia-mica, and magnesia-mica, each of which with now be described in turn.

Potash-mica or **Muscovite.** This contains no iron and is consequently of pale colours. In thin cleavage flakes it is transparent and almost or quite colourless. Thicker crystals may be grey (plate 68, fig. 2), greenish-grey (fig. 1), yellowish, brown, rarely green (fig. 3), or rose-red (fig. 7). The last-named colour is especially characteristic of lithia-mica, and the mineral of the occurrence represented in fig. 8 was formerly assumed to be a lithia-mica until it had been examined more closely. On the cleavage face the lustre

is bright and pearly, while other faces are dull and rough. The hardness is low (H. = 2), and the specific gravity about 3.

The cleavage flakes show in convergent polarized light a biaxial interference-figure (plate 4, figs. 3 and 4) with the two hyperbolic brushes widely separated, the optic axial angle being large. This angle in air varies from 60° to 70°. The plane of the optic axes is perpendicular to the plane of symmetry, so that muscovite is a mica of the first class. The strength of the double refraction differs greatly in different directions: on the basal cleavage it is low, whilst in sections across this it is strong. The reason for this is that while two of the principal indices of refraction have very nearly the same value, the third is widely different. Thus the values for sodium-light were determined as 1·6068, 1·6011, and 1·5718. The difference between the first and second of these is only 0·0057, but between the first and third the difference amounts to 0·0350. Thin cleavage flakes therefore give in parallel polarized light interference-colours of low orders, whilst thin sections across the cleavage polarize in colours of high orders.

Potash-mica when of ideal purity contains: silica (SiO_2), 45·3; alumina (Al_2O_3), 34·4; potash (K_2O), 11·8; water (H_2O), 4·5 per cent., corresponding with the formula $H_2KAl_3Si_3O_{12}$. Often, however, it contains also small amounts of soda and fluorine. Before the blowpipe the mineral is fusible only with difficulty; and the flame is coloured violet by reason of the potash present.

Hydrochloric and sulphuric acids have scarcely any action on potash-mica, neither have the waters and solutions which percolate through the rocks of the earth's surface. For this reason the mineral is very resistant to weathering. On the contary, it often occurs as a secondary product of the weathering of other minerals, such as felspar, andalusite, garnet, tourmaline, corundum, and many others. It is, at the earth's surface, the most stable of the micas, and for this reason is of wide distribution. In association with quartz and felspar it occurs as an essential constituent of many granites, gneisses and mica-schists; and when these rocks are broken down by weathering agents it forms part of the debris of which the sedimentary rocks are built up. Only in lavas is it conspicuous by its absence: in these rocks its place is taken by magnesia-mica.

As a rock constituent muscovite usually has the form of small irregular scales often measuring not more than a few millimetres across. In the coarser grained rock known as pegmatite the sheets of mica are occasionally of considerable size—several feet across. Crystals of muscovite bounded by crystal-faces are of much rarer occurrence. They are usually embedded in the quartz of the rock (plate 68, figs. 1 and 7) or attached to the walls of cavities (plate 68, fig. 3).

Enclosures of other minerals in muscovite are frequent and of special interest. Growing along with the mica between its planes of lamination these foreign minerals have been constrained to take a thin, flattened form. Thus crystals of garnet, which are so characteristically rounded or grain-like in form, when found embedded in sheets of mica have the form of thin plates with an almost circular outline. Tourmaline is found as thin, flattened prisms, and quartz as mere films; whilst magnetite is usually so thin that it is brown and transparent. That mica is capable of exerting some influence over the crystallization of other substances is shown by the following simple experiment. An aqueous solution of potassium iodide when allowed to crystallize on a glass plate produces a crop of thick cubes. If, on the other hand, the solution is crystallized on a clean, fresh cleavage sheet of mica, the crystals of potassium iodide take the form of flattened octahedra: and not only this, but the tiny crystals are all regularly orientated in the same direction on the sheet of mica, one of their triangular edges being parallel to the optic axial plane of the mica.

As a rock constituent potash-mica is of such wide distribution that is possible to mention only a few of the more important localities. Attached crystals are found with rock-crystal in cavities in the granite of St. Gotthard, especially in the neighbourhood of the hospice; at Abühl in the Sulzbachthal, Salzburg; Mursinsk in the Ural Mountains; as crystals 25 centimetres in length and 15 cm. thick in the Ilmen Mountains; as beautiful green crystals in Lincoln Co., North Carolina (plate 68, fig. 3). Embedded crystals are more common; for example, in quartz from New Jersey (plate 68, fig. 1); the isolated crystal from Bamle, Norway (fig. 2); rose-red crystals from Goshen, Massachusetts (fig. 7). Plumose mica, often with very delicate forms, is found in the granite at Aschaffenburg, Heidelberg, Pressburg in Hungary, and near Dublin. Large sheets, occasionally measuring as much as 10 feet across, are found in the Indian mica mines in Bengal and Madras. The production of Indian mica in 1908 amounted to 2310 tons, valued at £73,124. Considerable amounts used for technical purposes are also produced at various places in the United States. The commercial mica obtained in large quantities from Canada and Ceylon is a magnesia-mica and not potash-mica.

Applications.— Mica (or perhaps gypsum, or both of them) was known to the Romans. According to Pliny it was used in place of glass for the windows of foundries and beehives. At the present time it is much used for the windows of oil-stoves, lamp chimneys, eye shields, and in fact for any purpose where a transparent material capable of withstanding considerable changes in temperature is required. Being a bad conductor of electricity, and on account of its flexibility, mica is now used in large quantities for the construction of electrical machinery of various kinds. For this purpose scraps of mica are often cemented together to form a material known as "micanite" or "micanite cloth". The preparation of mica for the market is quite a simple operation. The "books" of mica taken from the mines are easily split into sheets of the required thickness, and these are trimmed to size with shears.

A popular name for mica is *Maria-glass* (*glacies Mariae*), because spangles of mica have long been used for decorating statues of the Virgin. In popular usage it is often called talc, but this is quite a distinct mineral (p. 342). Again, clear sheets of gypsum are often mistaken for mica, but this is not flexible and elastic like mica, and when exposed to heat it becomes white and opaque.

Soda-mica or **Paragonite.** This is analogous to potash-mica in composition but with sodium in place of potassium. As small scales it forms a white, glimmering rock called paragonite-schist. This is found at Monte Campione, near Faido on the southern slopes of St. Gotthard; and is represented in plate 51, fig. 1, as the matrix of crystals of cyanite and staurolite. The mineral is also met with on the Island of Syra, and on Lake Superior in North America. It always occurs as a constituent of crystalline schists and is not of wide distribution.

Lithia-mica. Two kinds of mica contain lithium as an essential constituent: these are distinguished by the absence or presence of iron, the former being known as lepidolite and the latter as zinnwaldite. Both are easily fusible before the blowpipe and impart a crimson coloration, characteristic of lithium, to the flame. Lepidolite is more closely related to the micas described above, whilst zinnwaldite is more allied to the magnesia-micas.

Lepidolite is usually met with as scaly aggregates, and on this account it receives its name, from the Greek, λεπίς, λεπίδος, a scale. The words lepidoptera, lepidodendron, and many others are derived from this root. Distinctly formed crystals are of quite rare occurrence. In colour the mineral shows a wide range, being white, grey, greenish, rarely blue, but as a rule of a delicate shade of rose-red or peach-blossom-red. This characteristic

red colour is due to the presence of a little manganese. A fine scaly aggregate of lepidolite is represented in plate 48, fig. 8, as the matrix of rose-red tourmaline.

Of the alkalis contained in lepidolite, potash always predominates (9—12 per cent.); the lithia ranges from 3 to 6 per cent.; and in addition some specimens contain rubidium (up to 3·7 per cent. of rubidia Rb_2O, but usually much less) and caesium (up to 0·5 per cent. Cs_2O). Further, lepidolite almost always contains some manganese (1—$5^1/_2$ per cent. MnO); and fluorine is always present (4—8 per cent.). The percentage of silica ranges from 49 to 52, and of alumina from 20 to 30. The mineral is thus very variable in chemical composition, and only in part is it represented by the formula $(K, Li)_2Al_2Si_3O_9(F, OH)_2$. The best test for recognizing the mineral is to hold a small flake in the Bunsen-flame; it fuses quite readily to a white bead and imparts a crimson colour to the flame. The specific gravity is 2·8—2·9.

Lepidolite always occurs in connexion with granitic rocks, more usually in veins of granite-pegmatite, in which it is usually associated with red tourmaline (rubellite). It is not a mineral of wide distribution. A few of the more important localities are: Penig in Saxony; Rozena in Moravia; Schuttenhofen in Bohemia; Alabashka in the Urals; Mount Mica near Paris, and elsewhere in Maine, where blocks of a hundredweight have been found; Madagascar, etc. The largest deposits are those mined at Pala in San Diego Co., California (plate 48, fig. 8), where in 1901 the output of 1750 tons was valued at 43,200 dollars.

Applications. — The pretty rose-red spangled lepidolite from Moravia has occasionally been cut and polished in small slabs for making boxes, etc. The mineral is the most important source of lithium salts, which are used mostly in medicine. Rubidium and caesium salts are also extracted, but these are now mostly obtained from the mother-liquors of the Stassfurt potash-salts. These two rare alkali metals are present as traces in many mineral-waters, and it was in the mother-liquor from the brine of the Dürkheim spring that R. Bunsen discovered these chemical elements. From 240 kilograms of the mother-liquor, remaining from 44,200 kilos of the brine, he obtained 9 grams of rubidium chloride and 7 grams of caesium chloride. These metals give very characteristic flame-spectra, and it was during his classic work on spectrum analysis that Bunsen detected their presence in such small quantities. Lithium, the commonest of these three elements, is remarkable in being not only the lightest metal, but the lightest of all kinds of solid matter, its specific gravity being only 0·59. It is a silver-white metal which so far has found no practical application.

Zinnwaldite is a kind of lithia-mica containing iron. It receives its name from its most important locality, namely Zinnwald in the Bohemian Erzgebirge. It is sometimes found as large six-sided plates, but more often as small crystals grouped in fan-shaped aggregates. Containing a considerable amount of iron, the crystals are coloured yellowish-grey or brown, the colours being often arranged in zones, as is well shown in plate 68, fig. 8. In the crystal here figured we also see a series of fine lines perpendicular to the outer edges. Since this crystal is only a fragment taken from a close aggregation with other crystals, only two of the six possible edges are present, and correspondingly there are only two sets of the fine lines, and also only a portion of the zoning shown. This fine striation is the result of an intimate twin intergrowth.

The chemical composition of zinnwaldite may be explained by the mixture of the lepidolite molecule with a molecule of iron silicate, as expressed by the formula $(K, Li)_2Al_2Si_3O_9(F, OH)_2 + Fe_2SiO_4$. An analysis of zinnwaldite from Zinnwald gave the following results:

SiO_2.	Al_2O_3.	Fe_2O_3.	FeO.	MnO.	K_2O.	Li_2O.	F.	H_2O.
46·44	21·84	1·27	10·19	1·57	10·58	3·36	7·62	1·04 per cent.

Traces of rubidium, caesium, and thallium are also sometimes present. Before the blowpipe the mineral fuses readily to a black slag, and it imparts a crimson coloration to the flame. Specific gravity 2·9—3·1. The most important locality for zinnwaldite is Zinnwald in Bohemia, where it is found grown on quartz, together with cassiterite, fluorspar and scheelite, in the veins of tin ore. The crystals are not often so large as the one represented in plate 68, fig. 8, being usually 1—2 cm. across.

Magnesia-mica or **Biotite.** As a rule this mica is darkly coloured, either dark brown or dark green, and it is then readily distinguished from potash-mica: sometimes, however, the colour is as pale as that of potash-mica. Of the specimens represented in plate 68, the dark brown crystal in fig. 5 could not be mistaken for any other kind of mica; whilst the crystals in fig. 6 are so pale in colour that they might readily be confused with potash-mica, if one did not recognize the specimen as one of the very characteristic ejected blocks of Monte Somma, Vesuvius, in which potash-mica never occurs. The large crystal in fig. 4 might also from its light colour be mistaken for potash-mica, and only on closer examination would it be found to be a magnesia-mica.

The contrasting of potash-mica and magnesia-mica as done in the last paragraph is not quite correct, for both of them contain a considerable amount of potash, only the latter contains magnesia in addition. To avoid misunderstanding it is best to use the name muscovite in place of potash-mica. Of the magnesia-micas, those of a dark colour and rich in iron (magnesia-iron-mica) are distinguished as *biotite*, whilst the paler coloured with little iron are called *phlogopite*. The crystals in plate 68, figs. 5 and 6, belong to biotite, and that in fig. 4 to phlogopite. Many mineralogists regard phlogopite as a distinct species, and not as a variety of biotite.

These two kinds of magnesia-mica can be readily distinguished from muscovite by their optical characters. In convergent polarized light the black hyperbolic brushes of the interference-figure are very close together; in other words, the optic axial angle is small. In some brown biotites this angle is practically zero, so that the interference-figure instead of being as in plate 4, fig. 4, very closely resembles that in fig. 1. Such mica had for long been regarded as optically uniaxial, but closer investigation proved that, like all other micas, it is really biaxial and monoclinic. Another distinction is that biotite and phlogopite are micas of the second class, the optic axial plane being parallel to the plane of symmetry, whilst muscovite is a mica of the first class (p. 330). Darkly coloured biotite is strongly dichroic: this dichroism is not observable on the cleavage planes, but only in sections across the cleavage. To cut a cross-section from an isolated crystal would not be possible because of the perfect cleavage; nevertheless, we have plenty of opportunities of observing cross-sections in thin slices of rocks. These have a rectangular outline, often with frayed ends, and show sharp cleavage cracks parallel to their length. They sometimes very closely resemble longitudinal sections of hornblende*) crystals, but differ from these in always giving straight or very nearly straight extinction with respect to the cleavage cracks. When the section is rotated with respect to one of the nicol prisms, the strong dichroism in evident by the change in colour from pale yellow to dark brown.

Cleavage sheets of phlogopite sometimes show a peculiar optical effect when a small flame is viewed through them. Radiating from the centre of the source of light a bright six-rayed or twelve-rayed star is seen. This phenomenon, known as *asterism*, is caused by the presence of vast numbers of microscopically minute needles of rutile embedded in the mica along three or six directions.

*) In the explanation of plate 67, fig. 4, the crystal shown in thin section has been, in fact, incorrectly described as biotite, instead of hornblende. (Compare p. 323.)

Magnesia-mica, of all the micas, occurs in the best crystals. Those of biotite (plate 68, figs. 5 and 6) are mostly small with the form of thin, six-sided plates. The small faces on the edges are sometimes (on crystals from Monte Somma) so smooth and bright that the angles between them can be accurately measured, and the crystals so proved to possess monoclinic symmetry. On the other hand, crystals of phlogopite are usually of large size and with rough faces: they not infrequently show lines of the pressure-figure, as in plate 68, fig. 4. An enormous crystal of phlogopite, found in a mica mine near Sydenham in Frontenac Co., Ontario, measured $1^1/_2$ by 2 metres on the cleavage surface, while perpendicular to this the crystal had a length of over 5 metres ($16^1/_2$ feet). Such a crystal would be rather too large for a private collection of minerals.

The chemical composition of the magnesia-micas is very variable, since magnesia and ferrous oxide, and alumina and ferric oxide are mutually replaceable. A general formula expressing this is $(K, H)_2(Mg, Fe)_2(Al, Fe)_2Si_3O_{12}$, which is in agreement with the analysis of many biotites. An analysis, by F. Berwerth, of biotite from Monte Somma, Vesuvius, gave:

SiO_2.	Al_2O_3.	Fe_2O_3.	FeO.	MgO.	K_2O.	H_2O.	F.
39·30	16·97	0·48	7·86	21·89	7·79	4·02	0·89 per cent.

Here the percentage of ferric oxide is low, but in some other biotites this may be as high as 20. In phlogopite the iron is low, and the ratio of silica to bases is rather different than in biotite.

Biotite is the most widely distributed of all the micas. It occurs not only in granite, gneiss, and mica-schist, like muscovite, but also in volcanic rocks. In granites, etc., it takes the form of irregularly bounded scales or sometimes larger plates; whilst in volcanic rocks the small plates have regular six-sided outlines. Sharp crystals of brown biotite are especially found in volcanic ashes and sands; for example, in the Vogelsberg (plate 68, fig. 5), Westerwald, and Laacher See district in Germany, and in the Midland Mountains of northern Bohemia. The best crystals are those in the ejected blocks of Monte Somma, Vesuvius (fig. 6). Large crystals of phlogopite occur at South Burgess in Ontario, Hull in Quebec (fig. 4), and several other localities in Canada.

Besides occurring as a constituent of granite, syenite, diorite, minette, trachyte, porphyry, and basalt, gneiss and mica-schist, biotite is also developed in various rocks by the result of the contact action of igneous rocks; and phlogopite is especially characteristic of crystalline limestones. At the earth's surface, biotite is not so stable as muscovite. When exposed to atmospheric weathering it becomes bleached and is altered to muscovite or to a green chloritic substance.

Chlorite Group.

The minerals of the chlorite group, like those of the mica group, possess a perfect cleavage in one direction, and their crystals are six-sided in outline. Like the micas, they are also monoclinic in crystallization, but here it is possible that some of them may be really rhombohedral. The cleavage flakes, though flexible, are not elastic: and another important difference from the micas is in the absence of alkalis and fluorine. All the chlorites contain silica, alumina, magnesia, and water; in some species the magnesia is replaced by variable amounts of ferrous oxide, and the alumina by ferric oxide. Those containing iron are green or bluish-green in colour; and on this account the name

chlorite is applied — from the Greek χλωρός, green. According to differences in chemical composition and crystalline form the following more important varieties are distinguished.

Penninite. In its external form penninite shows rhombohedral symmetry. The simplest crystals (plate 68, fig. 10) are bounded by a very steep rhombohedron and the basal pinacoid. Parallel to the latter there is a perfect, pearly cleavage, but the natural crystal-face is rough, as shown in fig. 10. The angle between the rhombohedral faces is $114^1/_2{}^0$, and these form an angle of 104^0 with the base.

The optical characters of penninite are also in agreement with the rhombohedral form. Cleavage flakes show in convergent polarized light a uniaxial interference-figure (plate 4, fig. 1), but owing to the very low double refraction the rings are widely separated. In spite of this, many investigators hold that penninite is monoclinic, and they explain the uniaxial character by the presence of repeated twinning. The mineral is strongly dichroic: a transparent crystal when viewed through a rhombohedral face shows a deep blood-red colour, but when viewed through the basal plane the colour seen is bluish-green. Sections cut perpendicular to the basal plane show in the dicroscope brownish-red and green pairs of colours.

The hardness of penninite is low — about $2^1/_2$ on the scale. The specific gravity of a crystal from Zermatt was determined as 2·65. Analysis, by Hamm, of material from the same locality gave:

SiO_2.	Al_2O_3.	Fe_2O_3.	FeO.	MgO.	H_2O.	
33·71	12·55	2·74	3·40	34·70	12·27	per cent.

This composition can be expressed by the formula $H_8(Mg, Fe)_5(Al, Fe)_2Si_3O_{18}$. The mineral is decomposed by hydrochloric acid with the separation of silica.

Penninite occurs as attached crystals, which are often aggregated together in druses, in crevices in chlorite-schist and similar rocks. The locality of the typical mineral is Zermatt in Switzerland (plate 68, fig. 10): here, on the Rympfischwäng on the Findelen glacier, and on the Gornergrat, it is found as crystals, 3 to 4 cm. in length and thickness, in crevices in actinolite-schist and chlorite-schist, and is associated with crystals of magnetite, garnet, and calcite. Other localities are in the Binnenthal in Switzerland, the Ala valley in Piedmont, and the Zillerthal in Tyrol.

A variety of penninite coloured a rich peach-blossom-red by chromium (5 per cent. Cr_2O_3) is known as *Kaemmererite*. This is found on chromic iron-ore at Lake Itkul in the Urals, at Kraubat in Styria, and Texas in Lancaster Co., Pennsylvania.

Clinochlore. In external appearance clinochlore (plate 68, fig. 11) does not differ from penninite. The name signifies that the crystals belong to the monoclinic system; this degree of symmetry is sometimes suggested by the form of the crystals, but it can only be determined by goniometric measurement. A cleavage flake gives in convergent polarized light a good biaxial figure (plate 4, figs. 3 and 4), thus differing from penninite. All the other characters, however, resemble those of penninite. The colour is bluish-green. For comparison with the penninite analysis quoted above, the following, by Clarke and Schneider, is given of clinochlore from West Chester in Pennsylvania.

SiO_2.	Al_2O_3.	Fe_2O_3.	Cr_2O_3.	FeO.	MgO.	H_2O.	
29·87	14·48	5·52	1·56	1·93	33·06	13·60	per cent.

Calculating the ferric oxide and the chromic oxide with the alumina, and the ferrous oxide with the magnesia, this analysis gives the formula $H_8Mg_5Al_2Si_3O_{18}$, similar to that of penninite.

Clinochlore occurs as attached crystals, as large lamellar masses, and as fine scaly aggregates. In the last-named form it is abundant as a constituent of chlorite-schist, which

as the matrix of magnetite is represented in plate 29, fig. 1, and of perovskite in plate 40, figs. 1 and 3. The attached crystals are usually associated with garnet, magnetite, and occasionally with sphene (plate 40, fig. 10). They are sometimes placed singly on the matrix, or again they may be closely crowded together on the rock surface. By the approximately parallel grouping of small scales, rosettes and vermicular forms result.

The largest crystals of clinochlore are from West Chester in Chester Co., Pennsylvania; these have the form of six-sided plates (plate 68, fig. 11) or of thick crystals with triangular basal planes. Fine crystals are also found at Achmatovsk in the Urals, and smaller ones on the Mussa-Alp in the Ala valley in Piedmont, on the Schwarzenstein in the Zillerthal and near Pfitsch in Tyrol, at Kupferberg in the Fichtelgebirge in Bavaria, etc.

A variety of clinochlore containing but little iron, and of a yellowish-white or greenish-white colour, from the neighbourhood of Zlatoust in the Urals, is known as *leuchtenbergite* (plate 68, fig. 9). The close similarity between the crystals here represented and those of clinochlore in fig. 11 is at once evident. This mineral was so named, after Maximilian, Duke of Leuchtenberg, in the belief that it represented a distinct species.

Besides the few varieties of the chlorite group here described there are many others which have been distinguished by special names.

Chlorites often occur as secondary minerals resulting from the weathering of biotite, garnet, augite, etc. Earthy chlorite is sometimes used as a green paint; and the "green earth" of Monte Baldo near Verona, used for the same purpose, is in part composed of chlorite.

Olivine.

Olivine is a mineral of interest from several points of view. It occurs as an essential constituent of rocks of various kinds; and by its weathering it gives rise to certain widely-distributed secondary minerals. When found as clear, transparent pieces it has been used since early times as a gem-stone. Again, its presence in meteoric stones and irons, sometimes as bright crystals rich in faces, proves to us that the laws of chemical combination and crystalline structure are the same in other parts of the universe as in our own world.

The chemical components of olivine are silica, magnesia, and iron (ferrous) oxide, the two latter being present in variable and mutually replaceable proportions. An olivine specially rich in iron, found in the glassy basalt at Limburg in the Kaiserstuhl, Baden, has received the special name *hyalosiderite*. A small amount of nickel is frequently present in olivine; and it is a noteworthy fact that nickel ores often occur in association with olivine-bearing rocks—for example, the important nickel ore garnierite (p. 174). Traces of manganese and aluminium are also sometimes present, although these do not appear in the following analyses of olivine.

	SiO_2.	MgO.	FeO.	NiO.
I. Olivine from the Vogelsberg, Hesse .	40·09	50·49	8·17	0·37
II. Olivine from "The Orient"	39·73	50·13	9·19	0·32
III. Olivine from the Pallas meteoric iron	40·86	47·35	11·72	—
IV. Hyalosiderite from Limburg, Baden .	36·72	31·99	29·96	—

In all cases the composition of olivine can be expressed by the formula $(Mg, Fe)_2SiO_4$. The member of the series containing little or no magnesium, and with the formula Fe_2SiO_4, is known as *fayalite*; this is found in cavities in a glassy volcanic rock in the Yellowstone National Park in the United States, and in a granitic rock in the Mourne Mountains in

Co. Down, Ireland. The member at the other end of the series, and consisting of nearly pure magnesium silicate, Mg_2SiO_4, is known as *forsterite*; this is found as almost colourless crystals in the ejected blocks of Monte Somma, Vesuvius, and in some crystalline limestones of contact-metamorphic origin. These two extremes of the olivine group are, however, of exceptional occurrence, and they need not be further mentioned in this place.

The name olivine is applied to this mineral on account of its characteristic olive-green colour, which is often to be seen in the grains and nodules found embedded in basaltic rocks (plate 69, fig. 4). The isolated, clear crystals are usually pale yellowish-green (plate 69, figs. 1 and 2), and as gem-stones (fig. 3) are known as *chrysolite* and *peridot*. The name chrysolite as used by Pliny was applied to some other mineral, which was perhaps yellow topaz—really a more appropriate application of the term. Peridot is a name that has long been employed by French jewellers, and it is also adopted by French mineralogists instead of the name olivine.

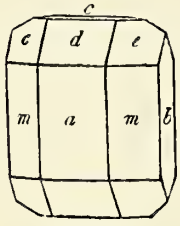

Fig. 238.
Crystal of Olivine.

Crystals of olivine belong to the rhombic system, and it is only exceptionally that they show more than a few faces. In text-fig. 238, m is the unit vertical prism ∞P, a the macro-pinacoid $\infty P\bar{\infty}$, b the brachy-pinacoid $\infty P\breve{\infty}$, c the base $0P$, e the primary pyramid P, and d the unit macro-dome $P\bar{\infty}$. These faces correspond with those seen on the crystal in plate 69, fig. 6, though here the base and the brachy-pinacoid are absent. The small crystals in figs. 1 and 2 are bounded by the large ortho-pinacoid, and in addition a brachy-dome in here largely developed.

Of much more frequent occurrence than crystals are irregular grains embedded in the rock; and these are usually easily to be recognized as olivine by their characteristic olive-green or oil-green colour. They are clear and transparent or only translucent, and possess a glassy lustre. The smaller grains show an irregular or sub-conchoidal fracture; but larger ones sometimes show even fractures, or cleavages, parallel to the faces of the two pinacoids. The hardness is about the same as that of quartz, and the specific gravity (3·3 — 3·4) near that of augite. When finely powdered, the mineral is completely decomposed by hydrochloric acid with the separation of gelatinous silica. The refractive power and the double refraction are high; the greatest and least indices of refraction being 1·697 and 1·661 for sodium-light.

The characters last named are of great assistance in the recognition of olivine when thin sections of rocks are examined under the microscope. A form of cross-section frequently seen is that represented in plate 67, fig. 5; in this figure the fine lines are cleavage cracks. In thin sections the mineral is colourless and transparent, and, owing to the high index of refraction, the surface appears rough and pitted. This roughness of surface is best seen when the nicol beneath the stage of the microscope is lowered in its holder (but for fig. 5 this was not done, in order that the clearness of the picture might be preserved). As a consequence of the strong double refraction, thin sections of olivine show brilliant polarization-colours between crossed nicols. Being a rhombic mineral the sections give straight extinction: the light is cut out when the longer (vertical) edges in fig. 5 are parallel to the vibration-direction of one or other of the nicols. Enclosures of other minerals in olivine are often to be seen under the microscope, grains and rounded octahedra of picotite (p. 226) being especially frequent.

Olivine is readily altered by weathering processes; water is taken up, and the mineral passes into serpentine. The large crystals represented in figs. 5 and 6, plate 69, though presenting the form of olivine, no longer consist of olivine substance, having been completely altered into serpentine: they are, in fact, pseudomorphs of serpentine after

olivine. The crystal in fig. 5 is a simple one with its original form well preserved. The two large crystals in the upper portion of fig. 6 are united in twinned postion along the brachy-dome $P\breve{\infty}$; but such twins are of extremely rare occurrence in olivine. The grains of olivine found embedded in rocks are very frequently more or less altered to serpentine; and in thin sections all the stages of the process can be followed. The olivine crystal in plate 67, fig. 6, with the same characteristic outline as that in fig. 5, shows an outer zone of serpentine, and the penetration of the same material along a network of cracks in the interior of the crystal. Some of the olivine still remains unaltered, but as isolated grains embedded in the network of serpentine. As the weathering proceeds the serpentine continues to grow at the expense of the olivine, until the whole crystal is transformed into the serpentine substance $H_4Mg_3Si_2O_9$. This chemical change is accompanied by the separation of iron in the form of magnetite or other oxide of iron, which collects along the network of cracks. By such a process rocks rich in olivine have given rise to serpentine-rocks.

Other modes of alteration of olivine are also known. For example, when the mineral is rich in iron, as in hyalosiderite and the olivine of some basalts, the product of weathering is limonite (hydrated iron oxide). In some rocks containing much calcium the olivine may be replaced by calcite; and in some diabases of Upper Devonian age this in the usual mode of alteration of the olivine.

Olivine forms an essential constituent of basalt and of other related rocks, occurring as embedded grains and small crystals (plate 67, fig. 5), either uniformly distributed throughout the rock or aggregated in nodular masses (plate 69, fig. 4). These aggregations in basalt consist mainly of olivine, together with pale-brown and grass-green augite and grains of black picotite. Bombs of such aggregated material are ejected by some volcanoes, and are found in abundance in the ancient crater of the Dreiser Weiher, in the Eifel. In rocks of another class, olivine is the predominating constituent; for example, in peridotite and picrite (plate 67, fig. 6), the latter being so named because of the large amount of magnesia, or bitter-earth, it contains. A rock known as dunite, from Dun Mountain in New Zealand, consists almost entirely of olivine. Isolated crystals of olivine are found at a few places loose in volcanic ash; for example, at Forstberg in the Laacher See district, and in the Auvergne.

The source of the clear olivine suitable for cutting as gems has long been shrouded in mystery; such specimens have usually been vaguely stated to be from "The Orient" or from Egypt. The locality of the specimen in plate 69, fig. 3 is given as Spyrget Island in the Arabian Gulf. Recently, however, a description has been published of the occurrence of clear crystals of olivine in an altered dunite on the small island of St. John in the Red Sea. Most of the gem-material probably comes from this island, where the mining, a monopoly of the Khedive of Egypt, is jealously guarded. Clear fragments and crystals of olivine are also picked up in the deserts of Arizona and New Mexico, particularly from the ant-hills. The large pseudomorphs of serpentine after olivine (plate 69, figs. 5 and 6) are from Snarum, near Modum in Norway. The typical iron-rich hyalosiderite is found in a glassy basalt at Limburg in the Kaiserstuhl, Baden. As a constituent of a meteoric iron, olivine is represented in plate 31, fig. 7.

Application. — Clear olivine is cut for use as a gem-stone, being then often known as chrysolite or peridot. It is remarkable for its perfect transparency and strong lustre, but owing to its yellowish-green colour and comparative softness it is not a stone of great value. From coloured glass of similar appearance it may be readily distinguished by its higher specific gravity: in bromoform olivine sinks, whilst glass floats.

Serpentine.

As already mentioned in the description of olivine, serpentine is an alteration product of that mineral, although at times it also arises by the weathering of some other minerals. It possesses no distinct crystalline form, but occurs as fibrous, columnar, foliated, or compact masses.

Fibrous serpentine is yellow of various shades, and on account of this colour and the fibrous texture it receives the name *chrysotile* (not to be confused with chrysolite, p. 338). It occurs as veins in compact serpentine (plate 69, fig. 7), the fine fibres being arranged perpendicularly to be walls of the vein. The close aggregation of the fine fibres gives to the mass a beautiful and very characteristic silky appearance. When, however, the mass is rubbed, the fibres are readily separated, and being very flexible they form a wool-like mass. Such material possesses the external characters of asbestos (that is, the true asbestos or hornblende-asbestos, p. 321) from which it is distinguished by the name *serpentine-asbestos*. It forms, in fact, the bulk of the commercial asbestos, which is obtained largely from the serpentines in the province of Quebec in Canada. Chrysotile is found in serpentine-rocks at many localities; for example, at Reichenstein in Prussian Silesia (plate 69, fig. 7), Friedensdorf in Nassau, and the Lizard district in Cornwall.

The columnar and foliated varieties, known respectively as *metaxite* and *antigorite*, are of less importance. The purer varieties of massive serpentine occur as separations in veins and crevices. Such material is usually pale in colour — grey, or yellowish-green to dark-green — with a banded arrangement of different tints; it has a splintery or conchoidal fracture, and in thin sections under the polarizing microscope is seen to consist of an aggregate of very fine fibres. This form is known as *picrolite* (plate 69, fig. 8) or precious serpentine, and is identical with the material of the pseudomorphs after olivine already mentioned. Compact serpentine also largely occurs as a constituent of the rock masses in which it has originated, being then intermixed with other minerals, such as augite, pyrope, etc., which have resisted the weathering processes. Such material is distinguished as common serpentine.

The formation of serpentine from olivine can be observed at any of the places where ancient igneous rocks rich in olivine crop out at the earth's surface. It is seen that the alteration takes place quite close to the surface and along fissures, and is evidently brought about by atmospheric agencies as in ordinary weathering. The appearance of the partly altered material as seen under the microscope has already been described (p. 339), and in this place it will only be necessary to say a few words as to the chemistry of the process. This may be represented schematically by the following equation: from two molecules of olivine we deduct one molecule of magnesia and iron oxide and add two molecules of water:

Olivine — Serpentine

$$2\,(Mg, Fe)_2SiO_4 - (Mg, Fe)O + 2\,H_2O = H_4(Mg, Fe)_3Si_2O_9.$$

The magnesia that separates combines with carbon dioxide to form magnesite, a mineral which as compact, white nodules is sometimes found in association with serpentine. The iron (ferrous) oxide becomes in part oxidized with the production of magnetite. The water that is taken up is not merely absorbed, nor is it present as water of crystallization, but is enters into chemical combination with the magnesium silicate, and it can only be expelled again at a red-heat. For this reason the formula of serpentine is written in the form as given in the equation above, rather than as $(Mg, Fe)_3Si_2O_7 \cdot 2\,H_2O$.

When free from iron, serpentine contains: silica (SiO_2) 43·5, magnesia (MgO) 43·5, and water (H_2O) 13 per cent. The amount of iron may reach 10 per cent., but only rarely exceedes this. By the addition of alumina, serpentine may become altered into chlorite — and this mineral may also be formed by the weathering of an aluminous magnesium silicate such as augite. A rock consisting originally of olivine and augite may thus be altered by weathering into a mixture of serpentine and chlorite.

Massive serpentine, often penetrated by veins of chrysotile, is of wide distribution. In Germany, it is met with in the Vosges, at Todtmoos in the Black Forest, at Biedenkopf and Dillenburg in Nassau, the Fichtelgebirge in Bavaria, as large masses at Zöblitz in Saxony, and at Reichenstein and Kosemitz in Silesia. In the Austrian Empire, at Pressnitz in Bohemia, Kraubat in Styria, etc. Other localities are Zermatt and elsewhere in Switzerland; Prato near Florence in Italy; near Ekaterinburg, etc., in the Urals. The greater part of the Lizard peninsula in Cornwall is composed of serpentine; and serpentine-rocks are also found in Anglesey and at several places in Scotland.

The olivine-rocks from which serpentine has been derived are frequently the home of useful minerals of various kinds; for example, diamond and pyrope, mispickel, magnetite, chromite, platinum, chrysoprase, and nickel ores.

Applications. — Serpentine-asbestos finds the same applications as the true asbestos (p. 321), but it is not capable of resisting high temperatures to the same degree, since it loses water and becomes brittle. Common serpentine is carved and turned into vases, lamp-stands, bowls, and a variety of ornamental objects, large numbers of which are made in Cornwall from the Lizard serpentine. Being compact and not very hard (H. = 3, as of marble) it is easily worked, and it takes a good polish. Formerly it was believed that serpentine acted against poisons, especially the vemon of serpents; and on this account apothecaries used mortars made of serpentine in preference to those of other materials.

Meerschaum.

In the worked form of bowls for tobacco-pipes and cigar- and cigarette-holders, meerschaum is known to everybody as a compact, white material with dull lustre and somewhat the appearance of ivory. It is well adapted for these uses, being fairly soft and readily cut, compact though light, and at the same time sufficiently porous to absorb moisture. Meerschaum is a German word meaning "sea-froth" or in French *écume de mer*. Mineralogists sometimes call this mineral by the name sepiolite, as suggested by a resemblance to the light, porous material known as the bone of the cuttle-fish or sepia.

Rough meerschaum is found in nature as irregular nodules. It is opaque and white, pale grey, or creamy in colour; and so porous that it adheres to the tongue and floats on water. On a fresh fracture it is dull and earthy in appearance; but when rubbed, even with the finger-nail, the surface becomes smooth and shining. The reason for this is that the particles of the soft, porous material become more closely pressed together.

The nodules, as found, are scraped free from earthy material with a special kind of knife, yielding peculiar shaped masses with rounded surfaces. The pieces are then air-dried, polished with wax, and sorted into various grades according to size and quality. Pieces too small and impure for carving are crushed and made into a paste with water. In this paste a sort of fermentation is set up by the addition of suitable organic matter,

and in this way the earthy impurities are separated. The purified paste is then pressed into moulds. The presence of organic matter in such articles of compressed meerschaum is demonstrated by the fact that when heated they blacken, and finally become white when more strongly burnt.

In its chemical composition meerschaum is closely related to serpentine; it contains the same constituents, but these are combined in other proportions, the formula being $H_4Mg_2Si_3O_{10}$. Like talc and serpentine, it is thus a hydrated magnesium silicate. Further, like serpentine, it is a product of weathering, representing perhaps a more advanced stage in the alteration; at any rate it is always found in association with serpentine.

Practically all the meerschaum that comes into the market is obtained from the plain of Eski-Shehr in Asia Minor, where it is dug from a number of shallow pits by the inhabitants of the Turkish villages. According to K. E. Weiss, a large part of the production at the present day is from the mines of Sarysu and Sepetchi situated between 20 and 30 kilometres to the east of Eski-Shehr at the foot of the hills bordering the wide valley of the Pursak-Chai (or Tembris river). The meerschaum-bearing rock is a soft, tuff-like breccia, which contains, in addition to the nodules of meerschaum, numerous fragments of serpentine and some of limestone. The majority of the meerschaum nodules are not larger than a medium-sized apple, and only exceptionally are they as large as a man's head. The pits vary in depth from 3 to 40 metres.

Other localities for meerschaum are of little importance. It is found in the Lyubic Mountains in Bosnia, and at Hrubschitz in Moravia.

The chief manufacturing centre of meerschaum goods is Vienna, but there is also a flourishing industry at Ruhla near Eisenach in Germany, whence smokers' requisites made of meerschaum and amber are sent to all parts of the world.

Talc Group.

Talc. Whilst some minerals are distinguished by their high degree of hardness, talc is remarkable for its softness; it is, in fact one of the softest of minerals, and is chosen to represent No. 1 in the mineralogist's scale of hardness (p. 51). For this reason it is greasy to the touch; and it is easily scratched, even by the finger-nail. The foliated or lamellar masses possess a perfect cleavage parallel to their large surface, and thin scales may be readily detached. These cleavage flakes are easily bent, and when released they do not spring back to their original position; so that the mineral, although flexible, is not elastic like mica. On the cleavage surfaces the lustre is markedly pearly in character. Distinctly developed crystals of talc are not known: the mineral occurs only as foliated (plate 69, fig. 13), scaly, or compact masses. The colour is white, yellowish, or more often a delicate shade of apple-green with a silvery appearance, as represented in the picture. The specific gravity is about 2·7. Thin cleavage flakes are transparent, and when examined in convergent polarized light they exhibit a biaxial interference-figure. In many of its characters talc shows a resemblance to the micas and chlorites, and, like these, its system of crystallization is probably monoclinic.

In chemical composition talc is related to serpentine and meerschaum in that it contains the same elements, but these are combined in other proportions. It is a hydrated magnesium silicate with the formula $H_2Mg_3Si_4O_{12}$, which corresponds with the percentage composition: silica (SiO_2) 63·52, magnesia (MgO) 31·72, and water (H_2O) 4·76. A small

portion of the magnesia may be replaced by an equivalent amount of ferrous oxide (up to 2 per cent. FeO). Like serpentine, talc is also a mineral of secondary origin produced by the alteration of other magnesium silicates. For this reason it is usually found in association with serpentine and chlorite, together with various other minerals (magnesite, dolomite, magnetite, and actinolite) formed as by-products by the same processes of alteration. Alone it forms the rock called *talc-schist*, and when intermixed with more or less chlorite it constitutes the scaly or compact *potstone*.

Talc is found in the crystalline schists of mountainous districts; for example, in the Zillerthal in Tyrol (plate 69, fig. 13), Mautern in Styria, the St. Gotthard district in Switzerland, in the Urals, etc.

Applications. — Owing to its smoothness and softness, powdered talc is much used as a toilet-power; for smoothing the floors of dancing rooms, and as a dry lubricant. Potstone may be turned in the lathe, and fashioned into fire-proof vessels or pots, and into fire-proofs slabs. In former times talc was used as a medicine.

Steatite. This is a compact, massive variety of talc, which owes its name to the fact that it is greasy or fatty to the touch: the popular German name Speckstein ("lard-stone") also has the same meaning. It is white, pale yellowish, or greyish in colour, and sometimes shows marble-like markings. It has a dull, earthy fracture, but when rubbed the surface becomes smooth and shining.

Although showing no crystalline form of its own, it not infrequently assumes the forms of the crystals proper to some other minerals. Such pseudomorphous crystals are of interest, and more especially so when we find that the original mineral which the steatite has replaced is the very resisting quartz. The six-sided pyramids shown in plate 69, fig. 11, have exactly the same characteristic form as the crystals of quartz represented in plate 51, yet the material of which they consist is opaque, dull, and quite soft: they are, in fact, pseudomorphs of steatite after quartz. Steatite also forms pseudomorphs after many other minerals; for example, dolomite, enstatite (plate 65, fig. 1), topaz, etc. A well-known locality for these pseudomorphs, and one which has yielded sharply defined specimens after a variety of minerals, is Göpfersgrün near Wunsiedel in the Fichtelgebirge, Bavaria. They occur in a bed of limestone, which, near its contact with granite, has been largely replaced throughout the whole of its mass by steatite, and the minerals contained in it have likewise suffered the same alteration. It is probable that the changes have been effected by hot solutions containing magnesium salts that emanated from the intruded granite.

Applications. — Steatite is the most suitable material for making the tips of gas-burners, since it can be readily cut into the required shape, and in the flame it does not fracture or fuse, but only becomes harder. The annual production in the Fichtelgebirge amounts to about 2500 tons of the value of £14,500. In Griqualand, South Africa, steatite is carved by the natives into tobacco-pipes.

Agalmatolite. This is a collective term applied to a variety of compact but quite soft minerals which are used by the Chinese for carving into idols and grotesque figures (plate 69, fig. 12). The name means in Greek "statue-stone"; and pagodite, another name applied in the same sense, was suggested by the miniature pagodas carved in these materials. These terms are thus descriptive of the uses of the material, rather than as defining the kind of mineral. They are analogous to the term asbestos (p. 321), which is often applied generally to any flexible mineral fibres that can be spun and are not combustible. As a matter of fact, at least three distinct kinds of minerals are employed for these Chinese carvings, and thus to be included under the general term agalmatolite.

One of these belongs to the species pyrophyllite, a hydrated aluminium silicate related to kaolin. Another is identical with steatite, a hydrated magnesium silicate. A

third has the same chemical composition of muscovite or potash-mica (p. 330). This variety of mica is composed of extremely fine scales and has been produced by the alteration of other minerals.

All these possess in common a close, compact structure, and yet they are so soft that they are very easily cut with a knife. In colour they are usually grey or greenish-grey, with splashes and veins of more pronounced red or green colours. These variations in the colour of the material are often skillfully utilized in the carving (plate 69, fig. 12).

Nothing is known as to the mode of occurrence of these materials; and indeed we known very little about the minerals of the vast Chinese Empire.

Cordierite.

In certain gneissose rocks there are sometimes to be seen yellowish and bluish, translucent to transparent grains possessing a glassy lustre, which at first sight might very well be mistaken for the common mineral quartz. When, however, these grains are examined more closely it will be found that one and the same grain shows a bluish or yellowish colour according to the direction in which it is viewed. The mineral is thus strongly dichroic, and cannot therefore be quartz. This peculiar character is exhibited much more strikingly by the rolled pebbles of the mineral from Ceylon; these show, when viewed successively in three different directions at right angles, one or other of the three colours dark-blue, pale-blue, and pale-yellow. When a dichroscope is employed any two of these colours can be seen simultaneously in the instrument. On account of this strong dichroism (or rather trichroism) the mineral is often known as dichroite. The name cordierite is after the French mineralogist P. L. Cordier, who was the first to notice the dichroism of this mineral.

In some of its characters, besides in its general appearance, cordierite shows a resemblance to quartz; the mean refractive index of 1·54, the low double refraction, the hardness of about 7, and the specific gravity of 2·6 all being very nearly the same as for quartz. These similarities are, however, accidental, for the two minerals are not in the least related to one another.

Crystals of cordierite (plate 69, fig. 10) have the form of short, stout prisms terminated by a large basal plane. Their faces are rough and the edges rounded; and good, sharply-developed crystals are very rare. The prism is often six-sided with quite the appearance of an hexagonal crystal; but measurement of the angles between these faces shows that we are dealing with a combination of a rhombic prism and a brachy-pinacoid. The angle of the rhombic prism is 119° 10′; and the crystals belong to the rhombic system. In the picture other prisms are also present, and all the faces in the prism-zone are deeply striated vertically: at the top, and perpendicular to the prism, is the large, rough basal plane.

Cordierite consists mainly of silica (51·36 per cent.), alumina (34·96 per cent.), and magnesia (13·68 per cent.); but a portion of the magnesia is always replaced by an equivalent amount of ferrous oxide (FeO 1—9 per cent.), and there may also be a small quantity of water present. The last constituent is probably due to a slight alteration of the mineral, for cordierite is very readily attacked by weathering processes, yielding potash-mica as a final product. Altered cordierite has at different times received a variety of names (pinite, gigantolite, fahlunite, aspasiolite, etc.) in the belief that distinct species were represented. The chemical formula of pure, unaltered cordierite is as yet not exactly known; the percentages given above correspond to $Mg_2Al_4Si_5O_{18}$.

In thin sections cordierite is colourless and transparent, and, the dichroism being now scarcely perceptible, the mineral may easily be mistaken for quartz. Cordierite is, however, frequently associated with the fibrous mineral sillimanite; and along fissures it usually shows a cloudiness due to a finely fibrous aggregation of altered material: quartz, on the other hand, is always perfectly fresh. Another characteristic feature of cordierite is the presence of pleochroic halos around spots in the crystal: these yellow halos are seen to come and go as the stage of the microscope with the section is rotated over the lower nicol-prism (the upper nicol being removed).

As already remarked, cordierite occurs as a constituent of certain gneisses, and as water-worn pebbles, clearly derived from the same rocks. It is also sometimes found in pyrites deposits in gneissose rocks. A well-known locality is near Bodenmais in the Bavarian Forest, where crystals associated with greyish-green felspar (plate 61, fig. 7) are found in pyrrhotite on the Silberberg. The large crystal represented in fig. 10, plate 69, is from Orijärvi in Finland, where cordierite occurs with copper-pyrites and iron-pyrites, specks of which still remain attached to this crystal. Other localities are: Cabo de Gata in Spain; Kragerö, Arendal, and Tvedestrand in Norway; Haddam in Connecticut; and, as smooth, rounded pebbles, in the gem-gravels of Ceylon.

Application. — The transparent, blue pebbles are cut as gem-stones, but care must be taken that the direction of cutting is such that the blue colour will be shown to the best advantage. On account of this colour, the mineral is also known as *water-sapphire* or *lynx-sapphire*, the former name being applied to pale coloured stones and the latter to those of a deeper blue. From the true sapphire (blue corundum) it is easily distinguished by its much lower hardness and specific gravity; it also possesses much less brilliancy of lustre, and is more strongly dichroic than sapphire.

Ilvaite.

The last mineral to be described in this section does not properly belong to the rock-forming minerals, for it is of quite exceptional occurrence. It is, however, a silicate, and as it is met with in very fine crystals it deserves mention in this place. As seen from fig. 9, plate 69, and text-fig. 239, the crystals belong to the rhombic system. They are bounded by two rhombic prisms ($M = \infty P$ and $S = \infty P\breve{2}$) the faces of which are striated vertically; a rhombic pyramid ($o = P$); and a macro-dome ($P = P\bar{\infty}$) which truncates the front edges of the pyramid. A small basal plane and a second macro-dome are also shown in fig. 9.

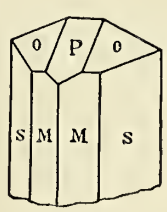

Fig. 239.
Crystal of Ilvaite.

The colour is iron-black, and fresh crystals display a very brilliant lustre. The mineral, however, weathers rather easily, becoming dull and brown, and finally passing into limonite. This alteration suggests the presence of iron; and, in fact, the mineral is richer in iron and poorer in silica than any of the silicates that we have considered. The essential constituents are silica, iron (ferrous and ferric) oxide, and lime, and in addition there are small amounts of manganese oxide and water. An analysis by Städeler of ilvaite from Elba gave:

SiO_2.	Fe_2O_3.	FeO.	CaO.	MnO.	H_2O.
29·34	20·84	34·12	12·78	1·01	2·43 per cent.

corresponding with the formula $H_2Ca_2Fe''_4Fe'''_2Si_4O_{18}$. Before the blowpipe, the mineral readily fuses to a black, magnetic bead. The specific gravity is 3·9—4·1.

The best crystals of ilvaite come from Rio Marina on the Island of Elba; and it is from the old name, Ilva, of this island that the mineral receives its name (another name, also in common use, is lievrite). The crystals are found in pockets in the iron ore, taking the place of haematite. The finest crystals are preserved in the Senckenberg Museum at Frankfurt-on-Main, and were long ago collected in Elba by the famous German traveller E. Rüppell: that represented in fig. 9 is one of this set.

Radiating and compact masses of ilvaite with small, thin crystals have been found in the neighbourhood of Herborn in Nassau. The two localities mentioned are the only ones of any importance for this mineral.

Mineral Salts.

General.

Amongst the minerals which we have so far considered there are many that are regarded by the chemist as salts, although they do not fall in with the popular idea of a salt. None of them have a salty taste and none (with the exception of copper-vitriol, p. 112) are readily soluble in water. The latter will now be dealt with, commencing with the indispensable common salt, the salt of salts; and then the potash-salts and saltpetre, of such importance as artificial fertilisers. Next we have the lime salts, which also are of importance in that they enter largely into the composition of the hard parts, the shells and bones, of animals. Finally, there are some other salts that find a variety of useful applications in technical processes.

We thus see that the minerals of this chapter are to a large degree necessary for the nutrition of plants and animals; and they are utilised in the great chemical industries, supplying, either directly or indirectly, products that are now almost necessities in every-day life.

The mineralogist, who attaches so much importance to crystalline form, will find in some of the minerals to be described very little of interest, since they occur only as unattractive, granular masses, and the enumeration of their essential characters need only be brief. Such salts may, however, play an important part in industry and agriculture, and they will consequently be treated here at somewhat greater length than in many of the textbooks on mineralogy.

If we consider for a moment the many and far-reaching applications of rock-salt and the potash-salts we begin to perceive the enormous extent to which these are utilized in the chemical industries. The raw materials of little value are converted by human intelligence, organisation, and work into products of greatly increased value; and when these products of chemical industry are utilized in connexion with agriculture they bring to a country more wealth than is yielded by the richest gold mines. Results such as these stimulate scientific research, and thereby the well-being and wealth of nations are increased.

Rock-salt.

When in ordinary life we speak of salt we mean the white, granular powder with which we savour our food, little thinking, perhaps, that it is one of the stones of the earth's crust. It is, indeed, a direct mineral product of nature, and may be obtained by simply crushing rock-salt: it is the only mineral that, without further preparation, forms part of our nutriment.

The pleasant saline taste is, of course, a characteristic feature of this substance; but there are several other characters which are of interest to the mineralogist, to whom, by the way, the mineral is often known as halite. The clear, spar-like masses obtained in salt-mines are seen to possess perfect cleavages in three plane directions at right angles

to one another, along which the mass is readily broken when struck with a hammer. The resulting fragments have the form of cubes; and further, we find that the three cleavages are equally perfect and not to be distinguished the one from the other. We may, therefore, conclude that these cleavage fragments are true cubes, and consequently that rock-salt crystallizes in the cubic system.

Natural crystals of rock-salt of a distinct form are not of frequent occurrence. A simple cube bounded by natural crystal-faces (not cleavage surfaces) is represented in plate 70, fig. 1: the fine cracks parallel to the edges of the cube indicate the presence of the cubic cleavage. Crystal-forms other than the cube are rare. Small octahedra (plate 70, fig. 3) are found embedded in carnallite; and on crystals obtained artificially from solutions containing urea a hexakis-octahedron has been observed. Such forms are, however, quite exceptional, and the simple cube is a highly characteristic form for rock-salt. Artificially formed crystals frequently show sunken areas on the cube faces, and in extreme cases the crystal may be shaped like a hopper or funnel (text-fig. 241, p. 354). As a rule, however, the mineral is found as cleavage and granular masses, often penetrated by strings of gypsum and anhydrite. Crevices in such massive material are sometimes filled by a fibrous form of rock-salt, the fibres being set perpendicularly to the walls of the crevice (plate 70, fig. 2). When intermixed with clayey material we have salt-clay.

In the cleavage cube of blue rock-salt shown in plate 70, fig. 4, there is seen at the upper right-hand corner a diagonally-placed surface perpendicular to the front face of the cube. This surface has the position of a face of the rhombic-dodecahedron, but it is not a natural crystal-face. It is a surface of secondary separation produced by the pressure of earth movements when the rock-salt was still buried in the rocks of the earth's crust. The same result can, indeed, be produced artificially by the application of pressure. To effect this a clear cleavage cube is placed diagonally in a vice so that two cube edges are held by the jaws: on turning the screw, the cube falls into two pieces along a diagonal parallel to a face of the rhombic-dodecahedron. One of the halves so obtained by artificial means is shown in plate 70, fig. 5; the striated and diagonally-placed surface (perpendicular to the front face of the cube) is the surface of separation. The separation has been brought about by the slipping of one half over the other along this surface, which is therefore known as a plane of gliding or *glide-plane*. This is quite distinct from a cleavage-plane; and any attempt to produce a separation in this direction by placing a knife diagonally across a cube face of rock-salt, and striking a sharp blow with a hammer, results only in the production of the usual cubic cleavage. There is, however, a very simple test which may be applied to ascertain whether a mineral possesses glide-planes. A blunt point — a nail often serves the purpose, or better still a steel punch with a rounded point — is placed on the surface to be tested, and the punch is struck a smart blow with a small hammer. On a cleavage face of rock-salt there are thereby produced two clean cracks perpendicular to the surface and each parallel to a diagonal of the cube face; the two cracks forming a four-rayed star about the point of percussion. The surfaces of these internal cracks are thus parallel to two faces of the rhombic-dodecahedron, and consequently have the same direction as the glide-planes produced by a simple pressure. This test is known as the punch test, and the figure produced is called a *percussion-figure*. A figure of the same character, but six-rayed instead of four-rayed, may be similarly produced on a cleavage surface of mica (p. 330).

When exposed to a moist atmosphere, rock-salt attracts water to itself; and this is especially the case when the salt contains some admixed magnesium chloride. The film of moisture so deposited on the surface dissolves some of the salt, and there are then formed, on a natural cube face or a cleavage surface, a number of small pits closely crowded

together. These pits, or *etched figures* (fig. 240), have the form of square pyramids sunk into the surface, each being bounded by four triangular planes inclined to the cube face at only a small angle. These new planes have the position of the faces of a flat tetrakis-hexahedron; and when they are abundantly developed on the edges of the cube they may produce a bevelling of these edges. The form is then a combination of the cube and a tetrakis-hexahedron, as shown in text-fig. 28. Such a form does not occur on a growing crystal of rock-salt, but only on a partly re-dissolved crystal. These forms of the etched figures prove that rock-salt possesses the full degree of symmetry of the cubic system.

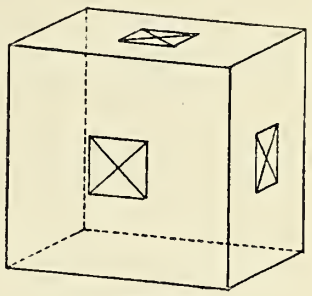

Fig. 240.
Etched figures on Rock-salt.

Chemically, rock-salt is sodium chloride and consists of 60·6 per cent. of chlorine combined with 39·4 per cent. of sodium, corresponding to the formula NaCl. In the colourless flame of the Bunsen-burner it fuses readily (at 775° C.) and colours the flame an intense yellow. This affords a simple test for distinguishing between the minerals rock-salt and sylvite, which are very similar in appearance: the latter gives a violet coloration to the flame. The yellow light of the sodium-flame is a homogeneous or monochromatic light, containing no rays of other wave-lengths. For this reason the sodium-flame is used as a source of light in determining the refractive indices and other optical constants of crystals. The interference-figures represented in plate 4 were photographed in sodium-light, since they are shown much more sharply in monochromatic light than in white light. A good sodium-flame may be obtained with a bead of fused sodium chloride supported in a loop of platinum wire; or still better by supporting the salt on a sheet of asbestos card, through a round hole in which the flame of the Bunsen-burner passes.

The fact that salt possesses a taste indicates that it is soluble in water; and it is indeed one of the most readily soluble of minerals. 100 parts of water are capable of dissolving 36 parts of salt. Unlike many other substances, the degree of solubility is only slightly influenced by the temperature: a boiling solution contains no more than 39 parts of salt in 100 parts of water.

It is well known that when salt is scattered on snow the latter becomes melted; and it is also common knowledge that when ice and salt are mixed together the mixture becomes extremely cold — such a freezing mixture being often used for making ice-cream. In a mixture of three parts of ice with one of salt the temperature falls to — 18° C.; this being the freezing point of a solution of sodium chloride in water of these particular proportions. With some other salts still lower temperatures are reached; for example, a mixture of calcium chloride and ice cools to — 37° C.

Being a cubic mineral, rock-salt is singly refracting and optically isotropic. This can be readily demonstrated by placing a clear cleavage fragment in the polariscope between crossed nicols: it remains dark in all positions. If a piece should show here and there feeble double refraction, this is the result of strain and proves that the fragment has been subjected to pressure. The index of refraction is low, being 1·5442 for sodium-light. Clear cleavage blocks of rock-salt are perfectly transparent, not only to light rays, but also to heat rays — in other words, the material is diathermanous to a high degree.

Amongst the colours shown by rock-salt, the blue presents points of special interest. It may range from a deep, intense blue to bright sky-blue (plate 70, fig. 4), or at times it may be of a purple shade. The intensity of the coloration often varies in different parts of the same piece of rock-salt, and sometimes shades off into colourless portions. When the salt is dissolved in water the colour disappears, and the same happens when the mineral

is heated. Chemical analyses have failed to reveal the presence of any known colouring matter in the material. The blue colour may be produced artificially by exposing colourless rock-salt to the action of cathode rays or by heating it in a vapour of metallic sodium. Attempts have been made by numerous investigators to solve this curious problem; much has been written on the subject, and various explanations as to the cause of the mysterious blue colour have been offered, but the matter has not yet been finally settled. According to one explanation, the colour is due to the presence of sodium subchloride Na_2Cl.

Other colours than the blue shown by rock-salt are due to the presence of mechanically enclosed impurities, which separate as a deposit when the salt is dissolved in water. Thus a red colour in rock-salt is due to intermixed ferric oxide, grey to clay or anhydrite, and brown to organic matter. These finely divided particles produce a cloudiness, or even opacity, in the rock-salt. Usually they are distributed throughout the mass without any orderly arrangement; but sometimes they are collected in layers parallel to the faces of the cube, so marking out a zonal structure in the crystal. A quite exceptional example of this is shown in the cleavage plate of rock-salt represented in plate 70, fig. 6. Here the mineral encloses crude bituminous petroleum, in alternately greater or lesser quantities as shown by the darker and lighter bands of colour. We see also that during the growth of the crystal there have been slight variations in its form: at times the edges of the cube were quite sharp, while at other times they were truncated. (A similar variation in form during growth is shown by the crystal of barytes in plate 76, fig. 2.) Rock-salt and petroleum are frequently found together in nature; and it has been assumed that salt plays some part in the formation of petroleum.

Enclosures of colourless liquid and of gas are also frequent in rock-salt. The cavities containing a liquid and a bubble of gas are sometimes of appreciable size, and the movement of the enclosed bubble can be readily seen as the specimen is turned about in the hand. The walls of these cavities are parallel to the cube faces of the enclosing crystal, and the cavities themselves are sometimes square or long and rectangular in shape. The liquid is a concentrated aqueous solution of salt, and the gases consist mainly of hydrocarbons; they are sometimes confined under a considerable pressure — corresponding to the pressure under which the rock-salt was formed. When such rock-salt, enclosing gases under pressure, is dissolved in water, the gas escapes with a crackling noise owing to the bursting of the cavities. Or when the salt is heated, the expansion of the gas causes the mass to burst, scattering fragments in all directions. Salt that behaves in this manner is called decrepitating salt (German, *Knistersalz*). When free from enclosures, salt does not decrepitate, even when heated to its melting point.

The specific gravity of rock-salt is quite low, being only 2·15. The hardness is also low, being slightly higher than that of gypsum.

Pseudomorphs after rock-salt, having the form of cubes with sunken faces, are not infrequently found on the surfaces of the bedding planes of shales and other rocks. These are not, however, alteration pseudomorphs produced by the decomposition of the mineral, but are due to the removal of the salt in solution. The material of the pseudomorphs is the same as that of the enclosing rocks. The mode in which they were formed must have been somewhat as follows. During a dry period, at the time when the rocks were deposited, the shores or mud flats of a salt-lake became dried up and the salt crystallized. Some of the crystals that were formed on the surface would perhaps become covered over with a layer of dust or fine mud, which on hardening in the sun would form a mould of the crystal. With the return of wet conditions the salt would be re-dissolved and the cavity filled with a new deposit of mud, and this finally covered over with a protecting layer of sediment, now represented by the next stratum of shale.

Occurrence and Origin. — Sodium chloride in a dissolved form is of extremely wide distribution in the waters of the globe. There is scarcely a brook that does not contain at least traces of salt in solution. Although the relative amount of salt present in fresh water is only minute, yet if the streams flow into a land-locked basin, where the solution will be concentrated by evaporation, they give rise to an accumulation of salt and the formation of a salt-lake. Springs of salt-water also issue at the earth's surface at many places: the saline taste is perceptible when the amount of salt exceeds one per cent., but many springs contain much larger quantities. When we consider the vast amount of salt present in the ocean (with the ratio of land to water as 1 : 2·54), we see that, next to water, salt is the most abundant of mineral substances at the earth's surface.

Although this statement is true for dissolved salt, it does not hold good for the solid mineral, or rock-salt. The latter, owing to its ready solubility in water, is only exceptionally met with at the earth's surface. A hill of pure and compact rock-salt near Cardona in Spain has been quarried since the time of the Romans: and similar occurrences at the surface are known near the Ilek river in the Russian government of Orenburg, and at a few places in Transylvania. On the other hand, beds of rock-salt of enormous extent occur buried in the rocks of the earth's crust in several regions. In some of these beds extensive mines are worked, whilst evidence of the presence of others is given by salt-springs and the brine pumped up through bore-holes.

Rock-salt occurs mostly as thick beds and masses in sedimentary rocks, in association with deposits of gypsum and anhydrite, and protected from inflowing water by a covering of anhydrite, gypsum, or clay. Such beds of rock-salt are not confined to any one geological period, but occur distributed throughout the whole range of the sedimentary strata, as indicated in the following table*): —

Geological formation.	Locality.
Recent	Deserts and Steppes: Kirghiz Steppes; Arabia; South America.
	Salt-lakes: Dead Sea; Great Salt Lake, Utah; Caspian Sea.
Tertiary	Bedded deposits: Cardona in Spain; Wieliczka, Bochnia, and Kalusz in Galicia, Austria; Transylvania; Asia Minor and Armenia; Rimini in Italy; Louisiana.
Cretaceous	Salt-springs at Unna, Westphalia. South of Medea in Algeria.
Jurassic	Salt-springs at Rodenburg, Hesse-Nassau. Bex in Switzerland.
Keuper	Salzderhelden and Celle in Hanover; Lorraine; Hall in Tyrol; Berchtesgaden in Bavaria; Ischl and Hallstatt in Upper Austria; Aussee in Styria; Cheshire and Worcestershire.
Muschelkalk	On the upper Neckar and Kocher in Württemberg; Ernsthall, Erfurt, and Stotternheim in Thuringia.
Bunter Sandstone	Schöningen near Brunswick; Arnshall near Arnstadt in Thuringia.
Permian (Zechstein)	Gera, Artern (Thuringia), Stassfurt, Egeln, Vienenburg, Halle, Sperenberg; Segeberg (Holstein); Inowrazlaw (Posen); Ilek river (Orenburg).

*) From H. Credner, "Elemente der Geologie", 9th edit., 1902, p. 197.

Geological formation.	Locality.
Carboniferous	Kanawha river in West Virginia; Durham and Bristol coalfields in England.
Devonian	Saginaw valley in Michigan; Baltic Provinces; China.
Silurian	West Virginia; near Salina and Syracuse in New York State; St. Clair valley in Michigan; Ontario; Salt Range in India.

Although rock-salt is found in the formations of all periods of geological history, yet in particular districts the beds are limited to certain formations. This limitation suggests that during each period the geological and climatic conditions favourable for the accumulation and preservation of beds of salt obtained only in certain districts. Thus, as shown by the above table, these conditions prevailed in northern and central Germany during Permian times; in southern Germany at the time of the deposition of the Muschelkalk; in England and the Salzkammergut in the Keuper period; and in Galicia, Roumania, and Spain during the Tertiary.

In the rock-salt deposits the lowest stratum consists always of gypsum, above which are alternate layers of rock-salt and gypsum with thin seams of anhydrite, whilst the capping of the deposit consists of anhydrite, gypsum, or clay. At Sperenberg, near Berlin, the total thickness of these beds amounts to 1200 metres, whilst at Wieliczka in Galicia they attain a thickness of over 1400 metres (about 4600 feet).

Anhydrite and gypsum both consist, as we shall see farther on, of calcium sulphate, the former without and the latter with water. By the absorption of water, anhydrite becomes changed into gypsum, and the change is accompanied by a considerable increase in volume. This change has taken place more especially when the protecting covering of the deposit consists of gypsum rather than of anhydrite, and it has a particular significance in connexion with the preservation of the rock-salt deposits. When the protecting cover of anhydrite becomes cracked by earth movements, the fissures become filled up again by the swelling which accompanies the change from anhydrite to gypsum, and the percolating surface waters are thus excluded from the underlying rock-salt.

In a few districts, for example, between the Harz and the Thuringian Forest, the rock-salt is overlain by other salts — the so-called abraum-salts, to be described later — which are still more readily soluble in water. And only when these are present is a salt deposit a complete whole. Often, however, the formation of the deposit has not proceeded sufficiently far for these later salts to be laid down; or in certain cases if originally present they may at some later period have been re-dissolved and almost completely removed.

The mode of occurrence of beds of rock-salt leaves no doubt that they have been deposited from sea-water. A precipation of salt is, however, not possible in the open ocean, since the amount of salt present is relatively small. The water of the open ocean contains in 100 parts 3·433 parts of dissolved salts; and 100 parts of the solid salts contain 75·81 parts of sodium chloride, 3·62 of potassium chloride, 9·07 of magnesium chloride, 5·58 of magnesium sulphate, 4·73 of calcium sulphate, and 1·19 parts of sodium bromide. Sea-water is, however, so dilute a solution that these salts are not present as such, but are dissociated into their ions. Only when the solution becomes more concentrated are these combined, and when supersaturation occurs they separate as the solid salts.

Sea-water can only become supersaturated by extensive evaporation, and this can only take place in a closed basin or a land-barred gulf, such as the Dead Sea or the Kara-boghaz (in the Caspian Sea) of the present time. In former geological periods the constant variations in the outlines of the land and sea must have frequently given rise to

the separation of such basins and gulfs from the main sea; and in these the water would be evaporated and the salt solutions concentrated. The dissolved salts separate from the solution in an order governed by their degree of solubility and by the relative amounts in which they are present. First the more difficultly soluble calcium sulphate separates as gypsum, forming the base of the deposit; and then follows the predominating sodium chloride as rock-salt. At later stages calcium sulphate is deposited in the anhydrous form as anhydrite. The reason for this being that in the more concentrated solution the dissolved potassium and magnesium salts exert a sort of attraction for the water, and constrain the calcium sulphate to crystallize in an anhydrous state. The frequent presence of seams of anhydrite alternating with beds of rock-salt may be explained by variations in the degree of concentration of the solution, brought about no doubt by the partial breaking down of the land barrier and the admission of a further supply of sea-water; or due perhaps to climatic variations. To the salt miners these seams of anhydrite are known as year-rings, and they believe that each one of them marks a year's growth of the salt-deposit. But it is to be noted that these anhydrite seams are not present in all salt-deposits.

It remains to be mentioned that rock-salt is also found as a volcanic product. It at times forms a white crust on the lava or a loose powder in the crater, and only rarely are distinctly-formed crystals met with. It owes its origin to the action of the hydrochloric acid, present in the volcanic gases, on the lava. The crust of chlorides so produced is not pure sodium chloride, but is intermixed with greater or less amounts of calcium and iron chlorides. As compared with the rock-salt of marine origin, that of volcanic origin is of no importance.

Winning of Salt. — In places where the rock-salt outcrops at the surface it is quarried just like any other kind of stone. When buried beneath the surface it is obtained by ordinary mining operations, or it is pumped up as brine.

Salt mines display a grandeur such as is not seen in other mines, and those of Stassfurt in Prussian Saxony and of Wieliczka in Poland have long been famous for their sights. An opportunity of visiting a salt mine should not be missed, and the underground trip is easily and comfortably made. The visitor descends the vertical shaft for a distance of 400 to 700 yards with perhaps somewhat unpleasant swiftness. From the bottom of the shaft a short dry level leads us into an enormous vaulted chamber, the glistening white walls, roof, and floor of which consist of crystalline rock-salt — literally a crystal palace. Between the several chambers, formed by the excavation of the salt, huge pillars are left for the support of the roof. To and from the main shaft there is a constant stream of laden and empty wagons; the hauling being done by horses which live for years down the mines, or by electricity which is also employed for lighting. At the end of our wanderings we find a table with a snow-white covering of powdered salt and lighted with candles set in clear blocks of rock-salt. Here we are offered bread and salt, the ancient symbol of trust and friendship; and although enraptured by the beautiful surroundings we are glad to find that it is not salt-water that is provided to quench our thirst in this salt-laden atmosphere. After filling our pockets with fine pieces of clear rock-salt, we return up the shaft to the dazzling daylight.

In the Salzkammergut and the neighbouring districts in Austria, the salt is won by a method of leaching. Galleries are driven into the salt beds, and into these "sink-works" (German, Sinkwerke) or reservoirs, fresh-water is admitted and allowed to remain for several weeks until saturated with salt. The well-known mines at Berchtesgaden in Bavaria, which are fitted up for the convenience of visitors, contain a huge cavern formed in this way, at the bottom of which a salt-lake is to be seen. From the water so left standing for long periods there are often deposited beautiful groups of gypsum crystals with the

characteristic form of swallow-tail twins. The brine from these underground reservoirs is pumped up to the surface and is evaporated on the spot, or it may be conveyed in pipes to the salt-works. For example, some of the brine from Berchtesgaden is conveyed to Reichenhall and there, after being mixed with the brine from springs, treated in the salt-works. Here salt has been won in this manner for hundreds of years, whilst at Hallstadt in Upper Austria the graves of the salt workers date back to the first century before Christ. This method of winning salt forms a connecting link between the ordinary methods of mining and those of collecting brine from salt-springs and bore-holes.

At many places salt-springs issue at the earth's surface, and in other districts, for example, in Cheshire, the brine is pumped up through artificial bore-holes. The larger part of the salt of commerce does not consist of powdered rock-salt, but has been obtained from these natural and artificial brine-springs. As given by the solubility of salt in water a saturated brine should contain 27 per cent. of salt, but this maximum amount is never reached. One of the strongest brines is that of the natural spring at Reichenhall in Bavaria, which carries $25^1/_2$ per cent. of salt. As a rule, however, the brines from artifical bore-holes are the richest, whilst those of natural springs are often so dilute that they require considerable evaporation before the salt can be separated.

In the process of evaporating the brine, a saving of fuel is effected by first concentrating the more dilute solutions by exposure to the air. This is done in the "graduation houses", so called because the degree of concentration of the brine is measured by the graduations on the stem of a hydrometer. The method consists simply in allowing the brine to trickle over a stack of brush-wood and thorns, whereby a large surface is exposed to the air and evaporation accelerated. This is repeated several times, until the brine contains 18 to 26 per cent. of salt. During this process the less soluble calcium salts fall out of solution and form a thick, stony crust on the thorns. This material, known to the salt workers as thorn-stone, consists mainly of gypsum; when crushed, it is used as a manure.

The concentrated brine now passes to the boiling house, where it is further evaporated in large iron pans heated by fires or by steam. If the brine is allowed to stand undisturbed in these pans, the salt crystallizes out on the surface as large hopper-shaped crystals (text-fig. 241). These are built up of numerous minute cubes grown together in parallel position. They are square in outline with a deep funnel-shaped depression, and are weighted beneath by a solid cube of salt. They increase in size by the addition of material to the sides and base; and when the latter becomes too large. the floating crystals sink to the bottom of the pan. The specimen represented in the figure is from the salt-works at Friedrichshall in Württemberg. Crystals of this size are, however, unsuitable for use as cooking and table salt, and it is necessary to hinder their growth by stirring the evaporating brine. The minute crystals as they separate then fall to the bottom of the pan, and the salt is obtained as a fine, white powder. This when dried is ready for use, and is the brine-salt, boiled salt, or white salt of commerce. Being purer than the salt obtained directly from rock-salt, it is better and at the same time much more expensive. Rock-salt is worth on an average 4s. 6d. per ton, whilst for boiled salt the price reaches 27s. per ton.

Fig. 241.

Hopper-shaped crystal of boiled white salt. (The crystal is tilted forward, showing the interior of the square hopper-like depression: beneath is a solid cube of salt.)

In the drying rooms a concentrated solution of brine drips from the shelves and frames on which the salt is supported; and in this way remarkable hollow stalactites of salt are formed. These are very delicate and friable, and are not easily preserved: when taken

out of the hot drying room they absorb moisture from the air and melt away. In the old boiling house at Bad Nauheim, in Hesse, there are to be seen many very fine examples of these hollow stalactites. Here, as at some other health resorts, the salt-laden atmosphere of the graduation houses is inhaled by the invalid visitors.

The winning of salt from brine-springs and by leaching in underground reservoirs has been carried on for many centuries; and this ancient industry has left its mark in the names of places. "Hall" means in German "salt-works", and this word enters into the names of many places in Germany and Austria: for example, Hall, Halle, Hallein, Hallstatt, Reichenhall, Herzogenhall, and Friedrichshall, are all towns where the salt industry has been carried on or where the product has been marketed; Saale and Salzach are rivers along which the salt was carried; the Hallforst belonged to the salt-works for the supply of fuel; the Hallgraf possesses the mineral rights, and Hallburg is his castle. The workmen at the salt-works are called *Halloren*; and the *Heller* is a small coin formerly used in the salt towns. In the same way, "wich" as a termination in place-names is of frequent occurrence in the English salt districts; for example, Northwich, Middlewich, Droitwich, Dirtwich, Foulwich, Nantwich, and Shirleywich; and the buildings in which the salt is manufactured are known as wych-houses.

The largest and indeed inexhaustible supply of salt is that in the sea, the water of which contains on an average $3^1/_2$ per cent. of salts. Other salts besides sodium chloride are, however, present, and the unpleasant, bitter taste is due to the magnesium salts. Salt is won from sea-water on many coasts. At high tide the water is led into the ponds or salt-pans of the so-called salt-gardens or salterns, and there allowed to evaporate under the sun's rays. The product is the well-known sea-salt or bay-salt. The ancients inhabiting the coasts of the Mediterranean knew of no other kind of salt, and in the Homeric and early Roman periods the inland inhabitants were without even this form of salt. The salt-works established by the king Ancus Marcius (640—616 B. C.) were on the sea-coast at Ostia, and the produce was carried on the Via Salaria into the Sabine country. Also in later classical times the sea was the only source of salt, and even to the present day the industry flourishes in the Tyrrhenian and Adriatic Seas. Much salt is also now collected during the warm summer months on the Atlantic coasts of France and Portugal (see below, for the production of sea-salt in France).

Although a considerable amount of salt is collected from the sea, still larger quantities are obtained from salt-lakes, such as those lying to the east and north of the Caspian Sea, of which the best known is the Elton salt-lake, and from the salt-saturated steppes of the same region.

Production of salt.— The United States takes the first place amongst the salt-producing countries of the world: the quantity obtained from rock-salt, brine-wells, and by the evaporation of sea-water during the year 1908 amounted to 28,822,062 barrels of 280 pounds (= 3,660,608 metric tons), valued at over $1^1/_2$ million pounds sterling. Next come Germany, Russia, and the United Kingdom, each with an annual output of very nearly two million tons, the exact amount varying from year to year, so that sometimes one country and sometimes another takes the first place. In the United Kingdom the bulk of the salt is obtained from brine-wells in Cheshire, Staffordshire, Durham, Lancashire, Worcestershire, Yorkshire, Co. Antrim, and the Isle of Man. In Russia there are extensive deposits of rock-salt in the Bachmut district in government Ekaterinoslav; and lake-salt is obtained in large quantities in the governments of Bessarabia, Kherson, Taurida, and Astrakhan. France produces rather over a million tons per annum; and here the greater part is sea-salt obtained from the Mediterranean along the coasts of the departments Bouches-du-Rhône and Gard. The total production of sea-salt in France during

1908 amounted to 391,072 metric tons, valued at £ 251,316, whilst for the year preceding the production exceeded half a million tons. The production of salt in India also exceeds a million tons per annum; and Japan, Spain, Italy, and Austria also contribute considerable amounts. The total production of the whole world amounts to 13 or 14 million tons per annum.

Uses of Salt.— Of first importance is the use of salt in the preparation and flavouring of food. Water and salt are not only the most abundant of mineral substances, but they are also essential for the nourishment of man and animals. Water without salt is unpalatable, and indeed when absolutely pure it acts as a poison. The water of the poison-spring at Gastein in Salzburg has, owing to its purity, a deleterious effect on the digestion. Salt is essential for the formation of the gastric juice that promotes digestion. It has been estimated that an adult man requires 7·8 kilograms (17·2 pounds) of salt annually. Another important use of cooking salt depends on its property of preserving animal and vegetable matter from decay, and large quantities are for this reason used for salting fish and meat.

Being an essential commodity, salt has since ancient times been subjected to a tax, and it has in many countries proved a fruitful source of revenue. In Germany at the present day the tax on culinary salt amounts to £6 per ton, whilst the value of the salt itself is only 27s. With an annual consumption of 420,000 tons, this gives to the state a revenue of $2^1/_2$ million pounds sterling. In order to prevent the use of cattle salt for household purposes the untaxed salt is rendered unpalatable by the addition of train-oil, iron oxide, and wormwood; and that intended for industrial purposes is treated with train-oil and lamp-black, or with sulphuric acid and ammonia.

Besides being given to cattle, salt is used in agriculture as a fertilizing agent. Sodium chloride is not necessary for the growth of plants, but it acts beneficially in the soil by converting the combined calcium and potassium salts into a more soluble form. The use of salt for this purpose is, however, not extensive.

In various industries and technical processes salt finds numerous applications. In the pottery works it is used for producing the glaze; in the leather industry it enters into the composition of the tanning liquor; in the manufacture of colours pure salt is used for precipitating the colouring matters from their solutions. But more especially it forms the material from which all other sodium preparations are derived; and it is also the most important raw material for the preparation of chlorine and hydrochloric acid. The latter, known popularly as spirits of salt, has many applications.

At the present day chlorine is obtained principally by the electrolysis of sodium chloride: it is liquified under pressure in steel cylinders and in this form is extensively employed for many purposes. It is used for bleaching vegetable fibres in fabrics and paper, for disinfecting and sterilizing, and mostly for the manufacture of bleaching powder used for the same purposes. Another product of the electrolysis of sodium chloride is sodium, but in the aqueous solution this at once gives rise to the formation of sodium hydroxide or caustic soda. The latter is employed as a reagent in the chemical laboratory, and in large quantities for the manufacture of soap and in the colour industry. Caustic soda is also produced in the soda works, and some works now manufacture it in place of soda. By the electrolysis of fused caustic soda in iron pots provided with a porous partition metallic sodium is obtained. This is a silver-white, soft and easily fusible metal, which is so readily oxidized in the air and so readily attacked by water, that it must be kept in petroleum or other indifferent liquid. It is much used in organic chemistry as an energetic reducing agent.

The most important product obtained from rock-salt is *soda* or sodium carbonate. This is used as a reagent in the chemical laboratory, for washing purposes, in the manufacture of glass (p. 273), and very largely in the colour industry. Soda occurs in nature,

but not in sufficient quantities to supply all the demands, and hence the larger part used commercially has to be manufactured from salt. The mineral *trona*, of which the formula is $Na_2CO_3 . NaHCO_3 . 2 H_2O$, is found in the soda-lakes of Lower Egypt and Central Africa, and it separates from the salt-lakes of Merida in Venezuela, in the state of Nevada, and in south-eastern California — all of these districts supplying soda in commercial quantities.

Soda was formerly manufactured by the Leblanc salt-cake process, but now the Solvay ammonia-soda process has very largely taken its place. In the latter process a solution of sodium chloride — which in practice is the natural brine from the salt-wells or springs — is saturated with ammonia, and into the mixture carbon dioxide gas is passed. Sodium bicarbonate separates, and by heating this, soda is obtained. The carbon dioxide is generated by burning limestone, and the quicklime thereby formed is employed for converting the ammonium chloride or salammoniac that is formed in the solution back again into ammonia for further use in the process. Here the only raw materials used are salt and limestone, and there are no by-products; the process is a continuous one, and being simpler and cheaper than the older Leblanc process it is gradually replacing the latter. In the Leblanc process the salt is first converted into sodium sulphate by the action of sulphuric acid, with the formation of hydrochloric acid as a by-product. This change is expressed by the equation

$$2 NaCl + H_2SO_4 = Na_2SO_4 + 2 HCl.$$

The sulphuric acid (oil of vitriol) used in large quantities for this operation is manufactured from iron-pyrites, and this part of the process forms a branch of the soda works. The sodium sulphate is mixed with coal and limestone, and roasted. The coal reduces the sulphate to sulphide —

$$Na_2SO_4 + 4 C = Na_2S + 4 CO,$$

and the sodium sulphide reacts with the limestone, forming sodium carbonate —

$$Na_2S + CaCO_3 = Na_2CO_3 + CaS.$$

When the coal is present in excess this process results in the production of caustic soda instead of soda. For many years vast waste heaps of this calcium sulphide accumulated, but methods were later introduced by which the sulphur could be recovered and used again in the cycle of operations.

Calcined soda, from which the water of crystallization has been expelled by heat, is the form in which soda is employed in the chemical industries. *Crystal-soda*, such as is employed for household purposes, is sodium carbonate with ten molecules of water of crystallization ($Na_2CO_3 . 10 H_2O$). Since this contains 63 per cent. by weight of water it is not so conveniently transported. The total annual production of soda, caustic soda, and sodium bicarbonate amounts to about $1^1/_4$ million tons, or about 0·8 kilogram ($1^3/_4$ lb.) per head of the world's population. Of this amount Germany produces about 325,000 tons, France 150,000 tons, the United States 120,000 tons, Russia 82,000 tons, whilst the largest quantity is manufactured in England.

Still another important product manufactured from salt is *glauber-salt*, which is sodium sulphate with much water of crystallization, the formula being $Na_2SO_4 . 10 H_2O$. This salt occurs in nature in a few minerals; it is present in many mineral waters; and it separates from the waters of some salt-lakes. These sources are, however, insufficient to supply the demand, and, as with soda, the greater portion of the commercial material is obtained artificially from rock-salt. It is formed as a by-product in the manufacture of hydrochloric acid from rock-salt and sulphuric acid; and, as noted above, it is formed as an intermediate product in the Leblanc soda process. It is also obtained by the interaction of sodium chloride and magnesium sulphate at a temperature below 0° C. in the solution

which remains after extracting potassium chloride from carnallite (p. 363). A low temperature is necessary, since glauber-salt can only be formed below 16° C. The material obtained by the last method is very pure, being especially free from iron; and it is therefore used by preference for making colourless glass. Sodium sulphate is now largely used in the manufacture of common glass (p. 173), since it is cheaper than soda. It is also used in the preparation of ultramarine, in the cellulose industry, etc.

The exports from the German customs district during the year 1898 of artificial products derived mainly from rock-salt were of the following values: soda $3^1/_2$ million marks (about £ 175,000), caustic soda 939,000 marks, bleaching powder $1^3/_4$ million marks, and hydrochloric acid 600,000 marks. Far greater quantities were, however, consumed in the home industries, especially in the colour industry.

From the above brief account of the chemical industries we see how far-reaching and varied are the applications and uses of the mineral rock-salt.

Sylvite and the Abraum-Salts.*)

At Stassfurt, in the Prussian province of Saxony, now the centre of the salt industry, salt-works were long ago established, and during the eighteenth century they were of considerable importance. In the year 1839, however, operations ceased, since the weak brine could no longer be worked at a profit in competition with the richer brines and salt-deposits discovered in other parts of Germany. The Prussian government thereupon decided to put down a bore-hole at Stassfurt. This was commenced in 1839, and in four years the salt-bearing strata were reached at a depth of 256 metres; the bore-hole was continued for a further depth of 315 metres without reaching the base of the salt-deposit. The results obtained were, however, unexpected; for instead of brine saturated with sodium chloride, the bore-hole yielded a solution containing much magnesium chloride and potassium chloride. In spite of this, the government decided to sink two shafts for the purpose of opening up these salt-deposits, expecting that beneath the more soluble salts pure rock-salt would be found — and in this they were not deceived. These two shafts, known as the "Manteuffel" and the "von der Heydt" were started at Stassfurt in 1852, and in five years reached the rock-salt at a depth of 330 metres (1080 feet), after penetrating 42 metres of the potassium and magnesium salts. These more readily soluble salts were considered worthless, and their presence added to the difficulty of sinking; they were consequently known as abraum-salts, *Abraum* meaning in German, rubbish or waste material to be removed. Their great value was, however, very soon recognized, and now they are sometimes referred to as "Edelsalze" or noble salts. Not long before, the celebrated German chemist, Justus Liebig, had shown that potash is necessary for the nourishment of plants, and that it is extracted by them from the soil; and consequently if the soil is to remain fruitful its supply of potash must be replenished. When, therefore, the agriculturists began to inquire for potash, the abraum-salts very opportunely supplied their needs. The salts were treated by the chemical industries, and very soon the potash-salts became one of the most sought for products in mining operations. Other shafts were sunk; first at Leopoldshall in the duchy of Anhalt (1857), and afterwards at Westeregeln (1871),

*) F. Bischof, "Die Steinsalzwerke bei Stassfurt." 2nd edit., 1875. H. Precht, "Die Salzindustrie von Stassfurt und Umgebung." 4th edit., 1889. C. Ochsenius, "Die Bildung der Steinsalzlager und ihre Mutterlaugensalze." 1877.

Neu-Stassfurt near Löderburg (1877), Aschersleben (1882), Vienenburg near Goslar (1884), Bernburg on the Saale (1885), Thiede in Brunswick (1885), and others. It was also proved by borings that the deposits of potash-salts are of wide distribution in Thuringia, Brunswick, and Mecklenburg. In order to avoid an over-production of the material, the state works and those controlled by private individuals formed a syndicate for the sale of the salts, placing a limit on the production and fixing a uniform price. This arrangement has led to good results, especially as the industry connected with the potash-salts is practically confined to Germany. Outside that country they are met with only at Kalusz in Galicia and in the Salzkammergut in Upper Austria, but here in such small quantity that the occurrence is of little more than scientific interest.

The more important of the abraum-salts are the following: —

Sylvite, potassium chloride (KCl).

Carnallite, a hydrated double chloride of potassium and magnesium ($KCl \cdot MgCl_2 \cdot 6\ H_2O$).

Kieserite, magnesium sulphate with one molecule of water of crystallization ($MgSO_4 \cdot H_2O$).

Kainite, a hydrated double salt of potassium chloride and magnesium sulphate ($KCl \cdot MgSO_4 \cdot 3\ H_2O$).

Picromerite, a hydrated double sulphate of potassium and magnesium ($K_2SO_4 \cdot MgSO_4 \cdot 6\ H_2O$).

Polyhalite, a hydrated triple sulphate of potassium, magnesium, and calcium ($K_2SO_4 \cdot MgSO_4 \cdot 2\ CaSO_4 \cdot 2\ H_2O$).

In addition to the above, there are also present in the abraum-salts other salts containing no potassium. These, although of little or no economic value, possess a scientific interest and add to our knowledge of the salt-deposits as a whole. They include: —

Tachhydrite, a hydrated double chloride of calcium and magnesium ($CaCl_2 \cdot 2\ MgCl_2 \cdot 12\ H_2O$).

Bischofite, hydrated magnesium chloride ($MgCl_2 \cdot 6\ H_2O$).

Bloedite, a hydrated double sulphate of magnesium and sodium ($MgSO_4 \cdot Na_2SO_4 \cdot 4\ H_2O$).

Boracite, borate and chloride of magnesium ($2\ Mg_3B_8O_{15} \cdot MgCl_2$).

In the salt-deposits these salts are, as a general rule, ranged in the order of their solubilities. They are, however, always more or less intermixed with rock-salt and anhydrite, more especially in the lower layers, whilst in the upper layers the salts of greater solubility predominate. At many places the abraum-salts are themselves overlain by gypsum and anhydrite and a bed of younger rock-salt, the latter being in turn covered by gypsum and salt-clay. Disregarding these intermixtures and repetitions, the several beds of salts possess quite distinctive characters, and they can be subdivided into the following "regions" (passing from the top of the deposit downwards): —

1. *Carnallite Region*, 15—40 metres in thickness; with carnallite, sylvite, kainite, kieserite, bischofite, tachhydrite, bloedite, picromerite, and boracite.
2. *Kieserite Region*, about 60 metres in thickness; consisting of kieserite, together with carnallite, bischofite, rock-salt, and anhydrite.
3. *Polyhalite Region*, also about 60 metres in thickness; with polyhalite, rock-salt, and anhydrite.
4. *Anhydrite Region*, some hundreds of metres in thickness; consisting of the older rock-salt and anhydrite in frequently alternating layers, and forming the base of the deposit.

In the majority of salt-deposits only the last of these regions is represented; the others not having been deposited, or if originally deposited they were at some later period removed by solution. Complete and typical salt-deposits, such as those of the Stassfurt district, are not known outside Germany.

Most of the salts found in these deposits have been formed, like the rock-salt, gypsum, and anhydrite, by the evaporation of sea-water, but under especially favourable topographical and climatic conditions. Their constituents are all present in sea-water; and when the degree of concentration, relative proportions of the several components of the solution, and the temperature reach certain points, one or other of the complex salts may be formed and separate from the solution. The exact conditions necessary for the formation of these salts have been studied in detail by the celebrated Dutch chemist, J. H. van't Hoff, working with his pupils in Berlin. The important results of this work were published in a series of fifty-two memoirs;*) they are too complex and detailed to be given in this place. The salts as found in the deposits have not all been formed directly from the concentrated sea-water, but are the result of later changes. Water percolating through the beds along cracks and crevices has brought about many changes and interactions in these readily soluble salts, and in addition to those originally deposited there are others of secondary origin.

In this place we will give a brief description of the more important of the abraum-salts. Most of them, possessing neither distinctive form nor colour, are not recognizable by the eye alone; and, indeed, only the first and the last mentioned in the list above, namely sylvite and boracite, are suited for illustration on the coloured plates.

Sylvite or Sylvine. This is the potassium compound analogous to rock-salt, being potassium chloride (KCl) instead of sodium chloride. Formerly it was known only as a white, powdery encrustation on the lavas of Vesuvius; and fine, large crystals were first found in the abraum-salts of Stassfurt and Leopoldshall in Germany. As shown by the crystal represented in fig. 7, plate 70, the form is that of the cubo-octahedron, consisting of the cube and the octahedron each developed to the same extent (text-fig. 242). This combination is just as characteristic for sylvite as the simple cube is for rock-salt. The crystals thus belong to the cubic system, and to all appearance they possess the same degree of symmetry as do crystals of rock-salt.

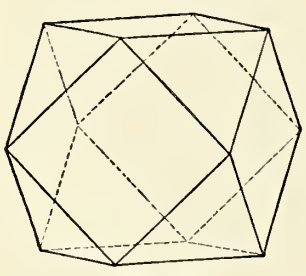

Fig. 242.
Crystal (cubo-octahedron) of Sylvite.

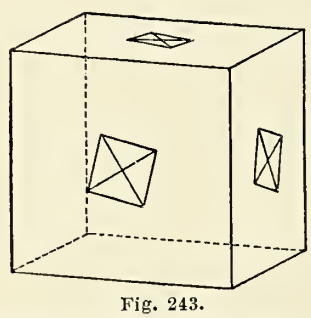

Fig. 243.
Etched figures on cleavage cube of Sylvite.

As proved by the orientation of the etched figures on the faces, the crystals of sylvite do not, however, belong to the holohedral division of the cubic system in which the full number of the possible elements of symmetry are present. The etched figures on the cleavage surfaces of sylvite are represented in text-fig. 243, and a comparison with text-fig. 240 (p. 349) will show that they have exactly the same form as those developed by solution on rock-salt; they consist of shallow pits with a square outline and formed by

*) J. H. van't Hoff, "Untersuchungen über die Bildungsverhältnisse der ozeanischen Salzablagerungen, insbesondere des Stassfurter Salzlagers." Sitzungsber. der Preuss. Akad. der Wissensch. zu Berlin, 1897—1908. A collected account has been published under the title "Zur Bildung der ozeanischen Salzablagerungen." (Braunschweig, 1905 and 1909.)

four isosceles triangles slightly sunk beneath the surface. We notice, however, that these etched figures are differently orientated in the two minerals with respect to the cube. In rock-salt the edges of the pits are parallel to the edges of the cube, whereas in sylvite there is no such parallelism; neither are the edges of the pits parallel to the diagonals of a cube face. From this obliquity of arrangement of the etched figures we can conclude that in crystals of sylvite there are no planes of symmetry perpendicular to the cube faces, and consequently an absence of all the planes of symmetry. On the other hand, the four-fold symmetrical arrangement is preserved on the cube faces, so that the three tetrad axes are still effective; similarly, the three triad axes and the six dyad axes are also present. This class of the cubic system, with the full number of axes but no planes or centre of symmetry, is known as the plagihedral-hemihedral or gyrohedral class. Crystals possessing this type of symmetry are exceptional, and only in a few instances (on cuprite) has any hemihedral development of the faces been observed.

In its other characters sylvite presents a striking resemblance to rock-salt. It possesses the same perfect cleavages parallel to the cube faces, and also the same degree of hardness (H. $= 2^1/_2$). Its specific gravity (1·9 — 2·0) and refractive index (1·490 for sodium-light) are, however, both slightly lower than for rock-salt. It is transparent and colourless, or sometimes reddish or of a fine blue colour as in rock-salt (p. 349); often however, the material is cloudy and white. The mineral is readily soluble in water; but its degree of solubility is more dependent on the temperature than in the case of rock-salt. One hundred parts of water at 0° C. dissolve 28 parts of potassium chloride, whilst at 100° C., 57 parts are dissolved. A hot, saturated solution of sodium chloride and potassium chloride deposits on cooling mostly potassium chloride; and by this means it is possible to separate the two salts when they occur mixed together. There is a marked difference in taste between sylvite and rock-salt, that of the former being much sharper. The two minerals may be readily distinguished by the colour they impart to the colourless flame of the Bunsen-burner: sylvite produces a violet coloration, whilst rock-salt gives an intense yellow. When the salts are mixed, the yellow colour completely masks the violet; but the latter can be detected by viewing the flame through a sheet of dark blue glass or a flask filled with a solution of indigo.

Crystals and large cleavage masses of sylvite are on the whole of rare occurrence. More usually the mineral occurs as granular masses forming nests or beds which may exceed a metre in thickness. Such granular material may consist of an intimate intermixture of sylvite and rock-salt, being then known as "sylvinite". A similar mixture containing also kieserite is known as "Hartsalz", but these terms are of loose application. "Hartsalz" occurs as dark brownish-red masses, frequently mixed with anhydrite, in which the sylvite is usually red or brown, the rock-salt colourless or grey, and the kieserite is white.

In the salt-deposits sylvite always occurs in association with carnallite, from which it has been derived. When carnallite is exposed to a moist atmosphere it absorbs water (owing to the deliquescence of its contained magnesium chloride) and it is thereby decomposed. The more readily soluble magnesium choride is removed in solution, to crystallize again as bischofite in deeper and drier parts of the deposit. The potassium chloride remains behind as a coarsely crystalline powder; and larger crystals are formed if the crystallization is slow and continued for a long period of time. In this way sylvite is now being formed in the mine galleries penetrating beds containing carnallite; and is found, sometimes as stalactitic or botryoidal masses, but more usually as a crystalline powder.

Besides being found at Leopoldshall and Stassfurt and elsewhere in the deposits of abraum-salts in Germany, sylvite is also known at Kalusz in Galicia, where it forms

lenticular masses and thin beds in the salt-deposits. In quite small amounts it has also been found at Berchtesgaden in Bavaria and Hallein in Salzburg. Its occurrence at these places suggests that abraum-salts were here also originally present, but that they have been subsequently dissolved and removed, leaving only traces of their former existence.

Application of Sylvite and other Potash-salts.— Potassium chloride, the richest of the potash-salts, contains theoretically 52·4 per cent. of potassium, and it is employed in enormous quantities in the chemical industries and in agriculture. Only a very small part of this is, however, supplied by the mineral sylvite, the bulk being obtained from the other abraum-salts, more especially carnallite. By a process of leaching and crystallization the latter yields a crude product containing about 80 per cent. of potassium chloride. This, together with "sylvinite", kainite, potassium sulphate, and potassium-magnesium sulphate, constitutes the potash-salts of artificial manures, now so indispensable in agriculture. These materials are exported from Germany to all parts of the world. Owing to cost of transport, it is mostly the more concentrated form of crude chloride that is exported, whilst the other salts, less rich in potassium, are used in the country of their origin. For agricultural purposes it is unnecessary that the salts should be specially purified; but they are sent out with a guaranteed minimum percentage of potash, and for the sulphates the amount of chlorine present is also stated.

About 75 per cent. of the production of potash-salts is consumed for agricultural purposes, the remaining 25 per cent. being used in the chemical industries. Potassium chloride is converted by the Leblanc process (p. 357) into potashes (potassium carbonate), formerly obtained by lixiviating wood ashes; this is employed in glass-making for producing a difficultly fusible glass, and for making a soft soap (potash soap). By the electrolysis of potassium chloride either caustic potash or metallic potassium and chlorine are yielded; and an electrolytic method is also employed in the manufacture of potassium chlorate. From potassium carbonate and coal the extremely poisonous potassium cyanide is prepared; this is used at the present day in large quantities in the extraction of gold from its ores by the cyanide process (p. 74). By the interaction of sodium nitrate (Chile saltpetre) and potassium chloride, potassium nitrate (saltpetre) is obtained, which possesses an advantage over the sodium salt in not attracting moisture from the air. With the disuse of black smoky gunpowder, much less saltpetre is now manufactured by this method than was formerly the case. Potassium sulphate is largely used for the preparation of alum; this finds many applications in dyeing, tawing, paper-making, medicine, etc. Still another artificially prepared potassium salt with important technical applications is potassium bichromate.

Production of Potash-salts.— The sales syndicate of the Stassfurt potash-works during the year 1898 disposed of 44 million hundredweights of potash-salts of the value of about $1^1/_2$ million pounds sterling. This amount included 1,056,226 tons of kainite and "sylvinite", 177,938 tons of crude 80 per cent. potassium chloride, 68,000 tons of carnallite with kieserite, 17,700 tons of potassium sulphate, and 10,500 tons of potassium-magnesium sulphate (48 per cent.). Further, 1900 tons of potassium cyanide of the value of nearly £200,000 were exported, and large quantities were also consumed in Germany. The potash-salt deposits of northern Germany are unique; no others of anything like the same extent and availability for working being known in any part of the world. For this reason Germany possesses a monopoly of the industry in potash-salts.

Carnallite. When pure, this mineral salt is colourless and water-clear, but often it is coloured by intermixed impurities, which remain as a fine, muddy deposit when the salt is dissolved in water. Particularly striking is the red carnallite with its intense colour

and metallic sheen, such material presenting quite the appearance of the artificial avanturine glass (p. 273). If a fragment of this variety of the mineral is dissolved in water and the residue examined under the microscope we see vast numbers of minute, yellow to brownish-red, transparent scales with beautifully-sharp six-sided or triangular outlines. These scales have been found to consist of the mineral haematite (p. 151). Sometimes we see, instead of scales, only a red, earthy mud; but in this case the red carnallite exhibits no metallic sheen. A suggestion that presents itself is that the carnallite has been so greedy for water that it has constrained the iron oxide to separate out in the anhydrous form. Still more remarkable is the presence in the insoluble residues of carnallite of minute crystals of quartz and tiny tetrahedra of boracite. To judge from the intensity of the colour of red carnallite one would imagine that it is very rich in iron; but as a matter of fact the mineral contains no more than 0·075 per cent. of haematite.

Pure carnallite has a specific gravity of 1·62, and contains potassium chloride 26·8, magnesium chloride 34·2, and water 39·0 per cent. The rarely-occurring crystals belong to the rhombic system, but they present the appearance of hexagonal forms. For their preservation it is necessary that they should be immediately placed in sealed, air-tight vessels. Pseudomorphs of rock-salt after carnallite have been found in the salt-clays of Westeregeln near Magdeburg.

Carnallite greedily absorbs water from a moist atmosphere, forming a solution of magnesium chloride whilst potassium chloride is deposited as minute cubes. On this difference in solubility of the two component salts of carnallite is based the commercial process for extracting the potassium chloride, of which carnallite is the most important source. The salt is dissolved in water, and as the hot, concentrated solution cools the potassium chloride is deposited. The remaining mother-liquor contains the magnesium chloride, together with traces of bromine and rubidium. Although the proportion of bromine present is relatively only minute, yet from the enormous quantities of carnallite that are worked for potash-salts bromine forms an important by-product. This is, indeed, the principal source of bromine, which finds many important applications; for example, in the preparation of eosine and other colouring matters, of potassium bromide used in medicine, and of silver bromide which is extensively employed in photography. The value of bromine and bromine preparations exported from Germany during 1898 amounted to £30,000, and still greater was the value of these materials used for home consumption. About 500 tons of bromine are produced annually in Germany, and from the American salt-springs about 400 tons per annum. This large production has caused a fall in price from about 50 s. per pound in 1865 to 3—4 s. at the present time. The enormous quantities of magnesium chloride liquor have so far not been utilized to any advantage; only to quite a small extent has this waste material been employed for the preparation of hydrochloric acid, chlorine, and magnesia.

Carnallite occurs in the uppermost layers of the beds of abraum-salts, it having been the latest product of deposition from the saturated solutions. The conditions necessary for its formation are that the solution should contain a large excess of magnesium chloride and that the temperature should not be much lower than 25° C. Long before carnallite had been found in the abraum-salts, its chance formation in the mother-liquors of the Bad Salzhausen had been described in 1826 by Justus Liebig (1803—1873). Little could the young German chemist have guessed that this new compound, to which be devoted some of his earliest work, would one day come to be of such importance in agriculture, and, indeed, largely help to put into practice his later teachings in agricultural chemistry.

Besides occurring in the salt-deposits of northern Germany, carnallite has been found in small amounts at Kalusz in Galicia, Maman in Persia, and in Colorado.

Kainite. This salt was first met with in the Anhalt shaft several years after the work there had been commenced, and being a new and unfamiliar material it was accordingly named from the Greek καινός, new. In a pure condition it forms white, pale yellow, reddish, or grey, translucent masses with a granular structure and somewhat resembling loaf-sugar in appearance. The pure salt has a specific gravity of 2·13, and contains potassium chloride 30·0, magnesium sulphate 48·2, and water 21·8 per cent. It is, however, in the larger masses always intermixed with kieserite, carnallite, rock-salt, and anhydrite. It occurs in the uppermost layers of the carnallite region, and at one time it was regarded as being always a secondary product produced by the interaction of the carnallite and kieserite with which it is found associated. The recent investigations of van't Hoff have proved, however, that kainite, like carnallite, can be directly deposited from evaporated sea-water. A portion of the kainite, and especially that which occurs in the kieserite region, has no doubt been formed by direct precipitation from sea-water; but the bulk of the material occurs in the salt-deposits in such a manner as to strongly suggest that it has been formed from the carnallite and kieserite. The latter appear to have been partly dissolved by percolating water and so converted into kainite. Here the kainite forms a covering over the carnallite, in a manner analogous to the "iron hat" of metalliferous veins (p. 72).

Raw kainite and also the potassium-magnesium sulphate prepared from this are the forms in which the potash-salts are principally used as artificial manures in Germany. The mineral is also employed for the preparation of potassium chloride and of potassium sulphate.

Kieserite. Magnesium sulphate separates from a pure aqueous solution with seven molecules of water of crystallization, forming the well-known epsom-salts or epsomite, $MgSO_4 . 7\ H_2O$. In the abraum-salts, however, magnesium sulphate occurs for the most part crystallized with only one molecule of water, $MgSO_4 . H_2O$, and combined as this hydrate it is the mineral kieserite. The reason for this is that magnesium chloride and other readily soluble salts, when also present in the solution, exert a sort of attraction for the water, constraining the magnesium sulphate to crystallize with less water than it would take up from a pure solution. As we have already seen (p. 353), the crystallization of calcium sulphate as gypsum or as anhydrite is governed in a similar manner by the presence of other salts in the solution. Under these conditions kieserite can be deposited at a temperature of 25° C. or less, but from a pure solution of magnesium sulphate it is not deposited at a lower temperature than 67° C.

Kieserite occurs as finely granular to compact aggregates of a greyish-white colour. In the pure condition it has a specific gravity of 2·52, and contains magnesium sulphate 87·1 with water 12·9 per cent. When exposed to the air it gradually becomes cloudy and finally falls to a white powder. This is due to the absorption of water from the air, and the conversion of the kieserite into epsomite. The latter is of rare occurrence in the abraum-salts, and it has no doubt always been formed as a secondary product by the alteration of kieserite. A massive variety of epsomite found at Leopoldshall has been called reichardtite.

In the abraum-salts the kieserite is always accompanied by carnallite, in which it forms strings and large nests. It often also forms a part of the "*Hartsalz*", which sometimes consists of a mixture of equal parts of kieserite and rock-salt (each 30—40 per cent.) with about 25 per cent. of sylvite and 1 per cent. of anhydrite. It is possible that "Hartsalz" represents still another compound salt with the formula $KCl . MgSO_4 . H_2O$, formed by the union of sylvite and kieserite, and containing mechanically intermixed rock-salt.

Of less importance than the "Hartsalz" is *picromerite* (also known as schoenite), which is a hydrated double sulphate of potassium and magnesium with the formula $K_2SO_4 . MgSO_4 . 6 H_2O$. It has been proved experimentally that this compound salt can be formed only at a temperature below 26° C. It occurs together with kainite, and has probably been derived from this. In the salt-deposits at Westeregeln picromerite forms a capping, 10 metres in thickness, on the kainite; and at Wilhelmshall it forms the base of a bed of sylvite.

In addition to its occurrence in the German abraum-salts, picromerite is also known from Kalusz in Galicia and Hallstatt in Upper Austria, sometimes as monoclinic crystals.

Owing to its high content of potash, "Hartsalz" is one of the most important of the salts for use as artificial manures. Like kieserite, it is also used for the conserving of stable manure: the magnesia it contains combines with the ammonia generated by the manure more readily than does gypsum, which is often used for the same purpose. Another application of kieserite is in the preparation of epsom-salts, which is largely employed in the dressing of fine cotton materials. The production of epsom-salts from this source amounts to 20,000 or 30,000 tons per annum. Considerable quantities of kieserite are obtained as a by-product in the extraction of potassium chloride from carnallite, remaining after the removal of the dissolved salts as a fine slime. With the evaporation of the water it hardens; and it is moulded into blocks and sold as block-kieserite, as distinct from the rock-kieserite (Ger. Bergkieserit) obtained directly from the salt-deposits.

Polyhalite. As indicated by its name, many salts (i. e. more than in the case of the ordinary double salt) enter into the composition of this mineral; these are potassium sulphate, magnesium sulphate, and calcium sulphate, together with water of crystallization, the formula being $K_2SO_4 . MgSO_4 . 2 CaSO_4 . 2 H_2O$. In the pure condition it contains 28·9 per cent. of potassium sulphate, and has a specific gravity of 2·72. The polyhalite found in the north German abraum-salts is pale grey and finely granular, whilst that from Ischl, Hallein, and Berchtesgaden is often brick-red and with a columnar structure.

Polyhalite occurs in the lowest region — the polyhalite region — of the abraum-salts. The bulk (about 90 per cent.) of this deposit consists of rock-salt, and in this the polyhalite forms seams with a thickness of 1—4 cm., similar to the seams of anhydrite. This salt differs from the other abraum-salts in its lower degree of solubility; and as compared with these its economic value is small. Another mineral salt closely allied to polyhalite is krugite: this differs in containing four, in place of two, molecules of calcium sulphate. It occurs as white or grey, finely granular masses.

Bischofite. This extremely deliquescent salt, $MgCl_2 . 6 H_2O$, forms white or yellowish masses with a granular or columnar structure. It occurs in part as an original deposit, and was formed, together with carnallite and kieserite, by the evaporation of the last of the mother-liquors. It also occurs, as previously mentioned (p. 361), as a secondary formation derived from carnallite. Another very deliquescent salt is one consisting of a combination of magnesium chloride with calcium chloride, namely *tachhydrite*, $2MgCl_2 . CaCl_2 . 12 H_2O$. This is the most easily soluble of the Stassfurt abraum-salts, and it therefore occurs only in the uppermost portion of the carnallite region. In most of the deposits it is, however, completely absent. It has been proved experimentally that this salt can only be formed at temperatures above 22° C., and we can consequently conclude that this must have been the minimum temperature at the time of the deposition of the abraum-salts which contain the tachhydrite. By such means modern chemical investigation is able to throw some light on the climatic conditions which prevailed in past geological epochs. Such conclusions can, however, only be arrived at when we are certain that the tachhydrite is an original deposit from the sea-water: in the case of the secondary deposits, where the

tachhydrite has been re-crystallized at some depth in the earth's crust, the temperature may very well have exceeded 22° C.

Bischofite is employed, like the waste magnesium chloride from carnallite, for the preparation of bromine and magnesia, and formerly also of chlorine and hydrochloric acid.

Sodium Salts. As compared with the potassium-bearing double salts, the sodium-bearing double salts which occur amongst the abraum-salts are of little importance; the most valuable of the sodium salts occurring throughout the whole of the deposit is always the rock-salt. A few of these sodium salts and double salts remain to be briefly mentioned in this place.

Bloedite (or astrakanite) is a double sulphate of sodium and magnesium with the formula $Na_2SO_4 . MgSO_4 . 4\ H_2O$, and is one of the few of the abraum-salts that occur in good, clear crystals. These are monoclinic, but they are of rare occurrence. More often the mineral forms granular aggregates which are colourless, yellowish, reddish or salmon-pink in colour. It shows a conchoidal or somewhat splintery fracture; but, like so many of the other salts, it presents no very striking characters to the unaided eye. Bloedite occurs as irregular masses, reaching a metre across, embedded in the kainite, "Hartsalz", or sylvite. It has probably been formed, at a period subsequent to the deposition of the salts, by the action of dissolved magnesium sulphate on the rock-salt. This mineral is met with in the abraum-salts of Stassfurt, Leopoldshall, and Westeregeln; in the salt-deposits of Ischl and Hallstatt in Austria, and as remarkably fine crystals in the Salt Range in India. It is also found in the salt-lakes of Astrakhan.

Loeweite is another double salt containing the same constituents as bloedite, but with less water of crystallization, the formula being $Na_2SO_4 . MgSO_4 . 2^1/_2H_2O$. This is of rare occurrence and of no technical value, and it is only mentioned in this place because it presents a point of scientific interest. A temperature of over 43° C. is necessary for its formation; so that its presence in the salt-deposits marks, like a minimum thermometer, the lowest temperature at which the deposition took place.

Mirabilite (or Glauber-salt) is the simple sulphate of sodium with ten molecules of water of crystallization, $Na_2SO_4 . 10\,H_2O$. This can separate from a solution rich in salt only at temperatures below 16° C. The occurrence of this salt therefore marks a point on the maximum thermometer, just as loeweite marks a point on the minimum thermometer. Mirabilite is deposited at the present time on the floor of the Gulf of Karaboghaz (also called Aji-darya) on the eastern coast of the Caspian Sea; but it is formed only during the cold winter months, whilst during the summer the deposit consists mainly of sodium chloride. For the same reason also, the manufacture of glauber-salt is only undertaken during the winter. In the German abraum-salts mirabilite occurs only in small amount and is of no practical importance: it has no doubt been here formed as a result of secondary changes. It occurs in large quantities at Logroño in Spain, Bompensieri in Sicily, and at few other places. The bulk of the glauber-salt used for industrial purposes is, however, a manufactured product (p. 357).

Thenardite (Na_2SO_4) is the form in which sodium sulphate crystallizes from a salty solution at temperatures above 16° C. Its crystals have the form of simple rhombic pyramids as shown in plate 78, fig. 12. These are at first water-clear, but on exposure to the air they absorb moisture and become cloudy. Thenardite is a mineral of rare occurrence in the deposits of abraum-salts. It is more frequently found as a deposit from the borax- and soda-lakes of Nevada, California, and Arizona; and especially in the sodium nitrate deposits of Chile, from whence came the crystal shown in the picture.

Glauberite is the anhydrous double sulphate of sodium and calcium, $Na_2SO_4 . CaSO_4$. This has been found in the German abraum-salts only in the massive form; but

fine large, monoclinic crystals are met with in the salt-deposits at Villarrubia in Spain, and in the Borax Lake in San Bernardino Co., California. These are colourless, white, or yellow, and have a specific gravity of 2·7—2·8. This mineral is of interest from an optical point of view: the biaxial interference-figure shown in convergent polarized light (plate 4, fig. 4) changes its form with rise in temperature; the hyperbolic brushes gradually approach one another and finally open out in the plane at right angles to their former position.

Vanthoffite, a double sulphate of sodium and magnesium, $3\,Na_2SO_4\,.\,MgSO_4$, is a new mineral recently detected in the abraum-salts at Wilhelmshall near Stassfurt. It was named in honour of the celebrated chemist, J. H. van't Hoff, whose work has thrown so much light on the mode of formation of the salt-deposits.

Boron Minerals.

In the readily soluble abraum-salts, but also in the gypsum and anhydrite of the salt-deposits, there occurs, often in some abundance, a mineral which is practically insoluble in water, but one which must obviously have been deposited from an aqueous solution. This is the mineral boracite. In respect to its insolubility it should scarcely find a place amongst the salts, but, since it occurs in the abraum-salts, it may conveniently be dealt with here; and at the same time we may mention some other minerals which contain the chemical element boron in large amount.

Boracite is of interest from several points of view; and especially by reason of the anomaly it presents in the lack of agreement between its crystalline form and its optical characters. The crystals (plate 70, figs. 9—12) are always small, and those measuring more than a centimetre across are quite rarities. Their form is that a cubic crystal with tetrahedral hemihedrism. Some have the shape of simple and sharply defined, though small, tetrahedra; others are richer in faces, with the tetrahedron, the cube, or the rhombic-dodecahedron predominating, and the other faces smaller in size. Although some of these crystals richer in faces may have the appearance of a holohedral cubic crystal, yet the hemihedrism is indicated by the number and arrangement of the smaller faces on the corners. Thus in text-fig. 244 a crystal of cubic habit is combined with the rhombic-dodecahedron and alternate corners are truncated by the tetrahedron. This corresponds to the natural crystal portrayed in fig. 11, plate 70, in which, however, the faces of the rhombic-dodecahedron are relatively rather wider than in the text-figure. In fig. 10 the same forms are also present with the addition of the second or complementary tetrahedron on the remaining corners. Here we have apparently a combination of the cube, the rhombic-dodecahedron, and the octahedron: but an examination of the actual crystal will show that these triangular faces corresponding to the octahedron are of two kinds, one set of alternate faces being smooth and bright, whilst those of the other set are dull and rough. The smooth, bright faces therefore belong to one tetrahedron, and those which are dull and rough belong to

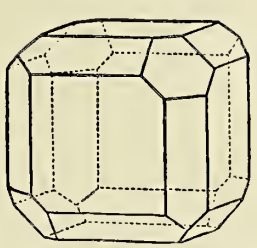

Fig. 244.

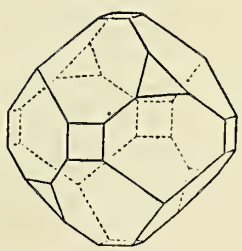

Fig. 245.

Crystals of Boracite.

the complementary tetrahedron; and the apparent octahedron is thus really a combination of the two tetrahedra. The crystal in text-fig. 245 is bounded by exactly the same forms as that in text-fig. 244, only here the faces of the rhombic-dodecahedron are large and those of the cube are small. This habit corresponds most nearly with the natural crystal represented in fig. 9, plate 70. In fig. 12, the crystals embedded in the matrix are bounded by only the rhombic-dodecahedron.

The typical forms of the cubic system being so beautifully and sharply developed on boracite, we should naturally expect the mineral to be singly refracting and optically isotropic. On the contrary, it is strongly birefringent, and a thin section when examined in polarized light displays brilliant polarization-colours. This discrepancy, first noticed by Sir David Brewster in 1821, long remained a puzzle to mineralogists. But in 1882 a French savant, E. Mallard, made the interesting discovery that when boracite is heated to a temperature of 265° C. the double refraction suddenly disappears, and the crystals are then truly cubic. On cooling again, the "optical anomalies" reappear. We can therefore draw the conclusion that the boracite substance is dimorphous, existing as a cubic modification above 265° C., and as a rhombic modification below this temperature. The crystals at the ordinary temperature, although still preserving their external cubic form, really each consist of a twinned aggregate of twelve rhombic pyramids with their bases forming the twelve faces of the rhombic-dodecahedron and their apices at the centre of the group.

The change from one modification to the other takes place at a perfectly definite and fixed point on the thermometer (265° C.), just as the change from water to ice, or vice versa, takes place at 0° C. Further, the change is a reversible one: on cooling, when the point 265° C. is passed, there is a conversion of the cubic modification into the rhombic; and with rising temperature, a transformation from the rhombic to the cubic modification takes place at the same point. Only one modification is thus stable at any particular temperature, and the two forms cannot exist side by side, as in the case of many other dimorphous substances, for example, diamond and graphite. Substances that exhibit this special kind of dimorphism are said to be enantiotropic. The mineral leucite (p. 299) and a few artificial salts (e.g. ammonium nitrate and silver iodide) behave in the same manner. These changes of state in a substance are particularly beautiful when watched under the polarizing microscope. They can be readily observed when a fragment of ammonium nitrate or of silver iodide is fused between a glass slip and a thin cover glass and allowed to cool on the stage of the microscope. The reverse change with rising temperature can only be studied with a specially constructed microscope provided with a heating stage.

In the case of leucite the explanation of the "optical anomalies" is quite simple, for here the mineral crystallized in the cubic form from a molten lava. Boracite, however, presents a difficulty, since its crystals are found embedded in carnallite and gypsum, which were deposited by the evaporation of an aqueous solution at the earth's surface; and, further, it is inconceivable that the salt-deposits could have been subjected to a temperature as high as 265° C. at any period subsequent to their formation. It is thus certain that the boracite substance could not have originally crystallized in the cubic modification, the very existence of which requires a temperature of not less than 265° C. Further, it may be remarked that the rhombic modification of the boracite substance has never yet been observed in simple crystals showing external forms characteristic of the rhombic system. The crystals are always complex twins of many individuals so united as to produce the external form of a cubic crystal. It thus seems probable that when the rhombic modification crystallizes (at temperatures lower than 265° C.) it is always constrained by twinning to produce an external form identical with that proper to the cubic modification. The production of pseudo-cubic forms by complex twinning has been observed in several

minerals; an excellent example, given by phillipsite, is illustrated by text-figs. 225—228 on pp. 305—306.*)

Another interesting feature presented by crystals of boracite is their pyro-electrical character, which was noticed by the Abbé Haüy so long ago as 1791. Like the pyro-electric crystals of hemimorphite (p. 131) and tourmaline (p. 245), crystals of boracite also exhibit a different development of faces at the two ends of certain axes (here the triad axes of the cubic crystal); and in consequence of this, together with the fact that the material is a non-conductor of electricity, the crystals develop positive and negative electrical charges at opposite ends of these axes when subjected to changes of temperature. A cube of boracite when warmed becomes positively electrified on four of its alternate corners, and negatively electrified on the remaining four corners; and when the crystal cools these charges are reversed. If a crystal so changing in temperature is dusted over with a mixture of red-lead and flowers of sulphur from a fine sieve, the distribution of the electrical charges will be marked out in red and yellow colours.

Crystals of boracite may be transparent with a bright and glassy surface, or they may be cloudy and dull. Their colour is white, grey, yellowish, or sometimes greenish. The specific gravity is 2·9—3·0; and the hardness is remarkably high, being equal to that of quartz. In addition to the crystals, bounded on all sides by faces, which occur embedded in carnallite and gypsum, boracite is also found in a massive form. This variety, known as stassfurtite, occurs as nodules, sometimes as large as a man's head, in the uppermost layers of the Stassfurt salt-deposits; it is white and earthy with much the appearance of chalk.

Chemically, boracite is a borate and chloride of magnesium with the formula $2Mg_3B_8O_{15} . MgCl_2$, and contains 62·5 per cent. of boric acid. It is soluble in hydrochloric acid, but practically insoluble in water. The conditions under which it was formed are not known.

The largest boracite crystals are those found embedded in gypsum on the Kalkberg at Lüneburg in Hanover, from which locality come the crystals figured on plate 70. Smaller crystals are found in gypsum at Segeberg in Holstein. Clear, sharply-developed tetrahedra, or tetrahedra with their edges narrowly truncated by cube faces, are obtained from the carnallite at Stassfurt; these vary in size down to microscopical dimensions. At the same place are also found pale greenish tetrahedra containing some iron, and known as iron-boracite. The earthy boracite, or stassfurtite, is collected to the extent of about 100 tons per annum, and is used for the preparation of borax and boric acid.

Some other borates are also present in the abraum-salts, but they are of rare occurrence. Others again, though not met with in the abraum-salts, are found in the salt-lakes of some other countries; and these being of some importance will be now mentioned as an appendix to boracite.

Borax, or tincal. This well-known salt is a hydrated borate of sodium with the formula $Na_2B_4O_7 . 10H_2O$. It forms monoclinic crystals which present a striking resemblance in their shape and angles to crystals of augite (p. 315). Here also the vertical prism of 87° is truncated by the ortho-pinacoid and the clino-pinacoid, and terminated by an obliquely-placed basal plane and pyramid faces. When fresh, the crystals are colourless

*) The peculiar case of boracite has given rise to much discussion, and various explanations have been offered; and it must be remarked here that the explanation given above differs somewhat from that given in the original German edition of this work. There it is suggested that the modification stable at the higher temperature may actually have crystallized out as such at the lower temperature; and in support of this is cited the case of the crystallization side by side of the two dimorphous modifications of potassium nitrate (described below, p. 373).

and transparent, but on exposure to the air they lose water and become cloudy and dull, finally falling to powder. Borax fuses easily in the flame, with an energetic bubbling, and gives a colourless glass. In this fused glass metallic oxides are readily dissolved, and in many cases they impart to it a characteristic coloration. On this property depends the use of the borax bead, formed in a small loop of platinum wire, in the blowpipe analysis of minerals. The use of borax in soldering also depends on its property of dissolving metallic oxides, thus preparing a clean surface for the adhesion of the solder.

A plate cut from a crystal of borax, in a direction parallel to the plane of symmetry, shows in convergent polarized light a biaxial interference-figure (plate 4, figs. 3 and 4), which is remarkable in the arrangement of the colours when viewed in white light. The figure is symmetrical only with respect to the central point; and borax affords the best example of this phenomena of crossed dispersion of the optic axes.

Borax is comparatively easily soluble in water, and it occurs in considerable amounts dissolved in the waters of certain lakes —the so-called borax-lakes. Borax crystals separate in the dried mud on the shores of such lakes in Tibet, California, and Nevada; and under these conditions it is found in association with thenardite (p. 366), gaylussite ($CaCO_3 . Na_2CO_3 . 5\,H_2O$), and other sulphates and carbonates.

Ulexite, or boronatrocalcite, occurs as white, ball-like nodules consisting of an aggregate of small pearly scales and fibres. It is found in the covering sands of the saltpetre deposits in Chile, where, from its resemblance to chalk, it is known as "tiza"; in the borate deposits of California it goes by the name of "cotton-ball". This material has the composition $NaCaB_5O_9 . 8H_2O$, and contains 43 per cent. of boric acid. The latter is separated commercially by blowing steam through a sulphuric acid solution of the mineral; or by boiling with soda solution, borax is prepared.

Sassolite is native boric acid (boracic acid), H_3BO_3, occurring in the free state. It forms loose, friable masses of small, pearly white scales, which are very soft and greasy to the touch. The masses are frequently tinged with pale yellow, owing to the admixture of native sulphur. Sassolite is only slightly soluble in cold water, but it dissolves easily in hot water, so that the crude mineral can be readily purified by re-crystallization. It readily volatilizes in steam, and this property plays an important part in the origin and in the winning of the mineral. At Sasso in Tuscany, and throughout the district extending between Volterra and Massa Marittima in the Italian provinces of Pisa and Grosseto, jets of steam highly charged with boric acid issue at the earth's surface, and are known in Italy as *soffioni*. For the purpose of collecting the boric acid, the steam is led into water, and the solution so obtained is evaporated. A perfectly pure product is prepared by converting the boric acid into borax and decomposing this with hydrochloric acid, when the boric acid separates as a fine scaly powder. Sassolite is also found in some volcanoes, particularly that of Vulcano in the Lipari Islands.

Boric acid also occurs as a constituent of some silicate minerals already discussed, namely tourmaline, axinite, and datolite. Of interest also, as being found as beautiful, colourless crystals is the mineral *colemanite*, a calcium borate $Ca_2B_6O_{11} . 5\,H_2O$, which is mined in California as a source of boron compounds. A closely allied mineral, but occurring in a massive form in large nodules, is the *pandermite* of Asia Minor' which is shipped from the port of Panderma on the Sea of Marmora.

An easily applied test for boric acid is afforded by the characteristic green coloration it imparts to the Bunsen-flame. Alcohol mixed with boric acid burns with a green-edged flame.

Applications of Boron Minerals.— The most important product obtained from these various minerals is borax, whilst sassolite is also employed in the preparation of pure

boric acid. Borax is extensively used for the production of starch glazes; in glass-making it is added to certain kinds of glass; in the pottery industry it is used for producing the glaze and as an addition to the colouring material. Boric acid is employed in medicine, as an antiseptic, and for preserving meat and fish; in the preparation of flint glass and the strass for imitations of precious stones; in the manufacture of candles, and in many other industries. The world's annual production of borax and boric acid amounts to about 14,000 tons, of which about 3000 tons are yielded by the Tuscan soffioni.

Nitrates.

The nitrates are salts readily soluble in water, and they are not often met with as minerals. The only ones of any importance are the sodium ($NaNO_3$) and the potassium (KNO_3) compounds. They are sometimes known collectively as saltpetre, a term more properly applied, however, to the potassium nitrate or nitre, the sodium salt being distinguished as Chile saltpetre or soda-nitre. The calcium salt (lime-nitre or wall-saltpetre) is sometimes seen as an efflorescence on the walls of stables. Barium nitrate, employed for producing the green fire of pyrotechnic displays, is known only as an artificial product. This salt crystallizes from an aqueous solution as beautiful, colourless, cubic crystals, which are optically isotropic and exactly similar to the crystals of the artificially-produced lead nitrate. Mixed crystals containing both barium and lead nitrates, however, possess the curious feature of exhibiting "optical anomalies".

Nitratine, Soda-nitre, or Chile saltpetre. This is an unattractive mineral forming granular masses intermixed with rock-salt, sand, and clay; such crude salt being known in Chile as *caliche*. Owing to the presence of the various impurities it may be white, grey, brown, yellow, or violet in colour. The purest white caliche contains 75 per cent. of nitratine with 20 per cent. of rock-salt; and in the brown material there is about 50 per cent. of nitratine and 40 per cent. of rock-salt, together with various other salts, sand, clay, and often some guano. Amongst the associated salts there are several which we have already noticed in the abraum-salts, for example, sylvite, thenardite, mirabilite, glauberite, epsomite, bischofite, anhydrite, and gypsum; whilst borates are here represented by ulexite.

In addition to these salts, two minerals containing iodine have been described from the nitrate deposits, namely lautarite (CaI_2O_6), and dietzeite ($7CaI_2O_6 . 8CaCrO_4$); but these are only very rarely met with and in extremely small amounts. Traces of iodine, probably in combination with calcium and with sodium, are, however, present throughout the caliche; and although the amount is only small, yet, from the large quantities of salt that are worked, this iodine forms a very important by-product. The Chilean nitrate deposits are indeed the principal source of iodine, which finds many important applications, not only in the form of the element, but also in the compounds potassium iodide, iodoform, and methylene iodide (p. 55). A ton of iodine costs about £1200, and in the year 1901 Chile produced 2460 tons.

The degree of solubility of sodium nitrate in water varies widely with the temperature. At 0°C. 100 grams of water dissolve 73 grams of the salt, but at 100°C. 180 grams are dissolved, and 110° C. as much as 200 grams. When a hot, concentrated solution cools it therefore deposits an abundant crop of crystals. On this property depends the method adopted for the purification of the crude salt; and by such re-crystallization a perfectly pure product is obtained. Pure sodium nitrate contains 63·53 per cent. of nitrogen pentoxide (N_2O_5) or 16·47 per cent. of nitrogen. It fuses at 320° C. and colours the flame yellow.

When heated with powdered charcoal it deflagrates and is completely dissipated. It absorbs water from a moist atmosphere; and it possesses a cooling saline taste.

The crystals grown artificially from a solution of sodium nitrate are rhombohedral in form, and they are in all respects strikingly similar to the rhombohedral crystals of calcite. They possess perfect cleavages parallel to the faces of the rhombohedron, the angles between which are 106° 30′ (corresponding to the angle 105° 5′ in calcite). Their double refraction is unusually strong, the refractive indices for sodium-light being for the ordinary ray 1·587 and for the extraordinary ray 1·336. On this account crystals of sodium nitrate would be suitable for the construction of polarizing prisms, but unfortunately it is not possible to obtain crystals, otherwise clear and colourless, free from enclosures of the mother-liquid. All attempts so far made to obtain large, clear, and perfectly homogeneous crystals of sodium nitrate, to take the place of the increasingly rare and expensive Iceland-spar, have been without success. Of further interest is the fact that when a drop of sodium nitrate solution is allowed to evaporate on a clean cleavage of calcite it deposits numerous tiny rhombohedra all arranged in parallel position on the calcite.

Occurrence. — The extensive deposits of soda-nitre in Chile were discovered about the year 1825, and since then the material has been worked in ever increasing amounts. It is found in the rainless districts of northern Chile, especially in the provinces of Tarapaca and Antofagasta. The saltpetre fields are situated in valleys and troughs at an elevation of 600—1500 metres above sea-level, and extend from Tarapaca in the north to Taltal in the south for a distance of nearly 400 miles. The surface of the deposits is usually covered with a snow-white efflorescent crust of impure glauber-salt, which serves as an indication of the presence of the nitrates. The upper layers consist of an ash-grey sand cemented by rock-salt, and beneath this is the caliche forming a bed never exceeding 1·5 metre in thickness. The base of the deposit consists of a bed of loose pebbles of quite recent geological age.

Extensive deposits of soda-nitre have also been reported to occur in California and Nevada. Those in California extend over a region from the Mohave Desert in San Bernardino County to Death Valley in Inyo County, and are said to crop out in beds 3 to 10 feet in thickness and to contain 15 to 40 per cent. of soda-nitre. These deposits have, however, not been exploited.

Beds of clay containing soda-nitre are met with in Egypt, and this material has been used, probably since early times, as a fertilizing agent. The so-called "tafle" found in the neighbourhood of Maalla and Esneh, on the Nile in Upper Egypt, is a clay containing 13—18 per cent. of soda-nitre and the same amount of common salt.

Origin. — Very little is known as to the mode of origin of the nitrate deposits in Chile. The associated minerals prove that the salts have been originally deposited from sea-water, and that at one time they formed part of a salt-deposit; but it is probable that they do not now lie in their original situation. The presence of nitrates and of iodates indicates that extremely energetic oxidation must have taken place; and W. Ostwald has suggested that, at the time of the formation of the deposits, some conditions favourable for the production of ozone in large amounts may have been effective.

Production. — The export of nitrates from Chile in the year 1830 amounted to only 800 tons, but in 1900 it reached 1,430,000 tons. Of this, the largest part, 1,129,000 came to Europe, and about 185,000 tons was used in America. In 1908 the output was very nearly two million tons, valued at about £9 per ton. The nitrates are subject to a heavy export duty, and bring to the state a revenue of 16—17 million dollars.

Application. — Soda-nitre is used extensively in agriculture as an artificial manure, and for corn and root crops it is the best and cheapest form in which nitrogen can be supplied.

Ammonium salts, obtained as a by-product in the manufacture of coke and coal-gas, hold their nitrogen in a form less readily assimilated by plants, and for this reason they are less useful as artificial manures. In Germany alone the annual comsumption of Chile saltpetre in artificial manures amounts to about 350,000 tons; and for the same purpose there are used 90,000 tons of ammonium sulphate, 600,000 tons of potash-salts, and in addition the phosphates to be considered later. In no other country are salts used in agriculture to such an extent.

Considerable amounts of Chile saltpetre are treated with potassium chloride at the Stassfurt salt-works (p. 362), with the production of potassium nitrate, and the nitrate is re-exported in this form to all parts of the world. By decomposition with barium chloride, barium nitrate is prepared (see under barytes). Another large proportion of the raw material is used for the manufacture of nitric acid (aqua fortis), which is obtained by decomposing the nitrate with sulphuric acid. By fusing sodium nitrate with metallic lead, sodium nitrite is prepared, a salt which finds extensive applications in the colour industry; and red-lead is prepared from the lead so oxidized.

It has been estimated that the Chilean nitrate deposits will become exhausted in about half a century, and fears have been expressed as to the shortage of supply of nitrates for use in agriculture. Recently, however, the fixation of atmospheric nitrogen, in the form of calcium nitrate, has been successfully accomplished and worked on a commercial scale; and the supply from this source is inexhaustible.

Nitre, or Saltpetre. Until the discovery of the deposits of soda-nitre in Chile, potassium nitrate was the only source of saltpetre. This nowhere occurs in such extensive and thick deposits as those in Chile; but, on the other hand, it is of far wider distribution, being rarely absent from the neighbourhood of human habitations. When potassium salts and decaying nitrogenous organic matter are present together in the soil the conditions are favourable for the formation of saltpetre. The potassium is supplied by silicates such as felspar or by wood-ashes, and the nitrogen is present in the form of ammonium compounds in dung and urine. By the action of nitrifying bacteria (*nitrosomonas*) in the soil the ammonium compounds are converted into nitric acid, and this combining with the potash gives potassium nitrate. In the dry weather this salt forms a snow-like efflorescence on the surface of the ground especially in the neighbourhood of villages. This is swept up and collected as crude saltpetre; but only in certain districts, where the material occurs abundantly, can the industry now compete with the Chile saltpetre.

Crude nitre is grey in colour, fibrous or earthy in texture, and much intermixed with impurities of various kinds. It is purified by re-crystallization from water. We have already seen that crystals of soda-nitre possess a great similarity to those of calcite; and now we find that crystals of potassium nitrate are remarkably similar to those of aragonite, which is the other crystalline modification of calcium carbonate. The text-figure of a simple rhombic crystal of aragonite given on a later page would do equally well for a crystal of saltpetre; and this salt shows the same forms as the simple (fig. 1) and twinned (figs. 5—8) crystals of aragonite shown on plate 74.

If we place a drop of a warm and slightly supersaturated solution of potassium nitrate on a slip of glass, the crystallization of the salt can be watched, and in polarized light some very interesting phenomena observed. At the edge of the drop there first separate small tables with a rhombic outline, these being rhombohedra resting on one of their faces. Next there appear long, spear-shaped crystals, which grow rapidly and soon reach the rhombohedral crystals. As soon as this happens the latter undergo a remarkable change: their outlines, previously straight and sharp, become crinkled, and on all sides spear-shaped crystals shoot out from their surface. The spear-shaped crystal are the more stable rhombic

modification of potassium nitrate, whilst the rhombohedral crystals represent an unstable modification of the same salt. We here see a transformation from the unstable into the stable form. At a temperature of 129° C. the rhombic modification is unstable, and passes over into the rhombohedral form. This experiment proves that of the two modifications of a substance the unstable form may first separate and later become transformed into the stable form; and this has perhaps a bearing on the peculiar case of boracite (p. 368).

Saltpetre occurs most abundantly in British India, and the quantity exported still amounts to about 20,000 tons per annum. It is also found in Hungary, Algeria, and many other countries, and also together with soda-nitre in the Chilean deposits. The artificial production of saltpetre, was formerly practised in saltpetre plantations or nitriaries. At the end of the eighteenth century, during the French revolution, large quantities of saltpetre were required for the manufacture of gunpowder; and an appeal made by the vigilance committee to science led to the suggestion by Gaspard Monge (1746—1818) that the material could be collected from stables, cellars, and closets. The results were surprising: in nine months twelve million pounds of saltpetre were collected, sufficient, and from a source at home, to supply the demand. The saying was: "Give us saltpetre earth and in three days we will load the cannons."

At the present day saltpetre is mostly produced from soda-nitre and potassium chloride (p. 362), and it is used largely for the manufacture of gunpowder and fireworks. Soda-nitre is not suited for this purpose, since it attracts moisture from the air.

Fluor-spar.

The minerals that we have just considered present little to attract the eye, and they are not suitable for pictorial representation; their forms and physical characters are of little moment; and their importance depends rather on their chemical composition and abundant occurrence. In fluor-spar, on the other hand, we have one of the most beautiful of minerals, one which in the clearness and colouring of its fine large crystals finds few rivals. But in addition to this, fluor-spar is also of importance from the economic side. Whilst rock-salt and the abraum-salts yield chlorine and bromine, and Chile saltpetre gives iodine as a by-product, fluor-spar is the main source of fluorine. These four chemical elements are known as the halogens, and their salts are called haloids.

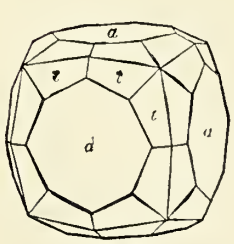

Fig. 246.
Crystal of Fluor-spar.

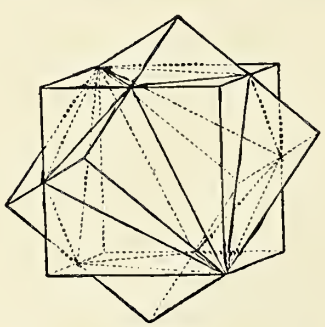

Fig. 247.
Interpenetrating twin-crystal of Fluor-spar.

From a glance at plate 71 it is clear that crystals of fluor-spar belong to the cubic system. The most frequent form is the cube (figs. 6—8, 11—13). The octahedron is also not rare, occurring either alone (plate 1, fig. 5; plate 71, figs. 2 and 3) or in combination with the cube (plate 1, fig. 3; plate 71, fig. 5). The faces of the cube are always smooth, whilst those of the octahedron are usually dull. Another combination very characteristic of fluor-spar is that of the cube and a hexakis-octahedron with the symbol $4O2$ (plate 71, fig. 9), which is shown more clearly in text-fig. 246, *a* being the faces of the cube and *t*

those of the hexakis-octahedron. Combinations of the cube with narrow faces of the rhombic-dodecahedron or a tetrakis-hexahedron (text-figs. 27 and 28, p. 24) also occur.

Twinned crystals are common, especially in the fluor-spar from the north of England. Two cubes grow together in such a manner that the corners of one project from the faces of the other, whilst they both possess an octahedral face (the twin-plane) in common (plate 71, figs. 8, 10, and 13; text-fig. 247). At the points where the corners break through the cube faces the latter are often raised into a low square pyramid bearing striations parallel to the edges of the cube (plate 71, fig. 13).

An important character of fluor-spar is the possession of four directions of perfect cleavage parallel to the faces of the octahedron. Perfectly regular octahedral cleavage forms (plate 1, fig. 6 and plate 71, fig. 1) can be readily obtained by splitting off the corners of a cube, These cleavage surfaces are smooth and bright, whilst the natural octahedral faces are usually rough and dull.

Fluor-spar displays, perhaps more than any other mineral, a remarkably wide range in its colours, as is well represented by the several figures on plate 71. There may also be wide differences in the depth of colour; for example, from the palest yellow to deep wine-yellow, from a light violet to an intense purple, from a delicate shade of green to a rich bluish-green. Frequently also, one and the same crystal may exhibit different colours or shades of colour in different portions. The crystals represented in plate 71 fig. 11 are yellow in their interior and blue in their outer portions; those in fig. 12 are violet along the edges; and those in fig. 2 blue on the corners. The small piece of massive, fibrous fluor-spar in fig. 14 shows alternating bands of green, violet, and white.

As if not satisfied with even this liberal provision of colours, certain crystals of fluor-spar possess the peculiar property of displaying a difference in colour according to whether they are viewed in light that has passed through the crystal or in light that has been reflected from their surface. This colour phenomenon, being well shown by fluor-spar, is known as *fluorescence*. The crystal represented in plate 71, fig. 10, when held between the window and the eye shows a pale green colour; but if it is viewed with the source of light behind the observer (i.e. in reflected light) the colour seen is a rich velvety purple. Such a feature cannot of course be represented in a picture, more than as a mere suggestion.

The richness of colouring in fluor-spar being often combined with perfect transparency we are reminded of the precious stones; and, indeed, there are many points in common between the colouring of fluor-spar and tourmaline (p. 246). Fluor-spar is, however, not at all suited for use as a gem-stone, since its hardness (No. 4 on the scale) is much too low, the mineral being softer than glass. Its refractive power ($n = 1{\cdot}4338$ for sodium-light) and colour dispersion are also low.

In addition to crystals, fluor-spar also occurs as fibrous, granular, or compact masses; these are generally of a light colour, but granular fluor-spar from Wölsendorf in Bavaria is bluish-black with a tinge of red. The mineral from this locality is further of interest in emitting a peculiar smell, resembling that of chlorine, when it is powdered in a mortar. This was formerly considered to be due to the presence of ozone; but recently it has been suggested that the smell is due to fluorine, an element not know to occur elsewhere in the free state.

The nature of the pigment to which fluor-spar owes its varied colours is unknown. It is present only in minute amounts, and is diffused throughout the colourless fluor-spar substance in an extremely fine state of division, in much the same way that a dye is held in solution. The fact that the colour is often destroyed when the mineral is heated to a temperature of 200° to 300° C., had led to the suggestion that the colours are due to hydro-

carbons; but there are various objections to this view. A perfectly colourless and water-clear crystal of fluor-spar is represented in plate 1, fig. 6.

Certain specimens of fluor-spar become luminous when heated to a temperature far below a red-heat, giving out a soft greenish or bluish light. This phenomenon, known as *phosphorescence*, is also exhibited by some other minerals, for example calcite, but we know little as to its cause. The green fluor-spar from Nerchinsk in Siberia (plate 71, fig. 1) displays a particularly strong phosphorescence when heated. Fluor-spar is only slightly transparent for the Röntgen rays.

In its chemical composition fluor-spar is quite simple, being fluoride of calcium with the formula CaF_2. When pure, it contains fluorine 48·72 and calcium 51·28 per cent. The presence of fluorine is readily demonstrated by adding sulphuric acid to the powdered mineral: hydrofluoric acid and calcium sulphate are thereby formed, and the former is recognizable by its penetrating odour and its property of etching glass. Other reagents have little or no action on fluor-spar; and yet we often find etched and deeply corroded crystals of the mineral which must have been acted upon by solutions in nature. The specific gravity of fluor-spar is relatively high, lying between 3·1 and 3·2.

Fluor-spar is a mineral of wide distribution, and in certain districts it is found in considerable abundance. It occurs most frequently in veins traversing granitic rocks and the rocks surrounding these igneous masses. In these cases the mineral has been deposited from the hot solutions which accompanied the eruption of the igneous rocks. Often, however, it occurs in sedimentary rocks, particularly limestones, quite independently of any igneous intrusions; and it has even been found in the interior of fossils. Here the mineral has no doubt been formed by the action of solutions containing soluble fluorides on the limestone rocks. The usual associates of fluor-spar are quartz (often present as a sparkling crust on the fluor-spar crystals), calcite, barytes, and metallic ores of various kinds.

The finest crystals of fluor-spar are those found in the veins of lead-ore in the north of England, particularly in a limited district on the borders of the counties of Cumberland, Durham, and Northumberland; namely in Weardale in Durham (plate 1, fig. 4; plate 71, fig. 10), at Allenheads in Northumberland (plate 71, fig. 8), and near Alston in Cumberland (plate 71, fig. 13). Fine specimens were also formerly found at many places in Cornwall (Menheniot, Redruth, St. Agnes, etc.), and at Beeralston in Devonshire. Fluor-spar is also of abundant occurrence in Derbyshire, but here usually as granular masses and as small, colourless crystals. The noted "blue-john", much employed for small ornamental objects, is found at Tray Cliff near Castleton in Derbyshire. This is a fibrous form of a rich purple colour with white and sometimes green bands; one variety is represented in plate 71, fig. 14.

Excellent specimens of crystallized fluor-spar are also found at many places in Germany. Beautiful, rich-yellow cubes and pale-yellow cubes with violet edges come from Annaberg in the Saxon Erzgebirge (plate 71, figs. 7 and 12). Good crystals are also found at Stolberg, near Wernigerode in the Harz Mountains (plate 1, fig. 3), and in the Black Forest in Baden (plate 71, figs. 9 and 11). An interesting occurrence is that in granite at Striegau in Prussian Silesia.

Cubes of a dark purple colour, and sometimes overgrown with colourless fluor-spar, are found together with tin-ore at Zinnwald in Bohemia (plate 71, fig. 4). Colourless fluor-spar is found in the neighbourhood of Meiringen in Switzerland; and the highly-prized pink octahedra are from the Göschenen valley in the St. Gotthard district (plate 71, fig. 3). Crystals of a delicate green colour come from Baveno in Italy (plate 1, fig. 5), and others of a peculiar reddish-violet from St. Gallen on the Enns in Styria (plate 71, fig. 5). Large green crystals have been found in considerable quantity at Macomb in St. Lawrence Co., New York.

Application. — At the present time colourless fluor-spar is much in request for optical purposes. Owing to its low refractive power and very low colour dispersion, it is especially suitable as a material for correcting the spherical and chromatic aberration of lens-systems. The so-called apochromatic microscope-objectives contain a lens of fluor-spar placed between lenses of glass. The specially clear and colourless fluor-spar from the neighbourhood of Meiringen has been worked by Professor Abbe for this purpose. The coloured varieties of the mineral, particularly the "blue-john" of Derbyshire, have been much employed as a material for small ornamental objects, such as vases, bowls, paper-weights, etc.; and it is supposed to have been the material of the famous murrhine vases of the Romans. Clear, richly coloured fluor-spar is no doubt sometimes passed off as a gem-stone, but owing to its low degree of hardness it is little suited for use in jewellery.

Fluor-spar is further the most important source of hydrofluoric acid and other fluorine compounds. When the powdered mineral is mixed with concentrated sulphuric acid there is an abundant evolution of hydrofluoric acid, and this is employed directly as an agent for etching glass. As a flux in smelting and in other metallurgical operations, fluor-spar has been used since early times; and indeed, its name, from the Latin (*fluo*, to flow), has reference to the property of the mineral of producing a fluid slag. In England, the annual production of fluor-spar amounts to about 40,000 tons, valued at 10s. to 20s. per ton; whilst in the United States some 50,000 tons are mined per annum.

Cryolite.

Cryolite carries a still larger amount of fluorine than fluor-spar, the pure mineral containing 54·4 per cent. of this element. This is combined with the metallic elements sodium (32·8 per cent.) and aluminium (12·8 per cent.). The chemical formula may be expressed as a double salt of sodium fluoride and aluminium fluoride, $3NaF.AlF_3$; but it is more probable that cryolite is the sodium salt of alumino-hydrofluoric acid, with the formula Na_3AlF_6. We thus see that, as with spinel, there are alternative ways of writing the formula of this mineral.

Cryolite is usually met with as coarsely granular or sparry masses, which are white and translucent, or rarely of a black colour. A peculiar moist-looking vitreous lustre renders the mineral easy of recognition. Other important characters are the three perfect cleavages approximately at right angles to one another, the low degree of hardness (H. = $2\,^1/_2$—3), the high specific gravity (2·97), and the easy fusibility. A thick piece of cryolite melts readily in the flame of the Bunsen-burner, to which it imparts an intense yellow coloration, proving the presence of sodium. The mineral is decomposed by sulphuric acid with the evolution of hydrofluoric acid, and the latter is readily recognized by its power of etching glass.

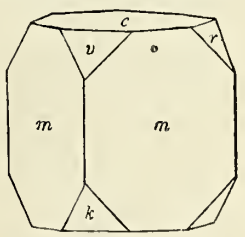

Fig. 248.
Crystal of Cryolite.

The characters just enumerated are sufficient for the identification of the mineral even in the absence of any crystalline form. Crystals are, indeed, not often seen; they always occur closely crowded together on the surface of the massive cryolite (plate 70, fig. 8). These crystals present quite the appearance of cubes, sometimes with truncated corners (text-fig. 248); but by accurate measurement they have been proved to be monoclinic. The faces *m* of the vertical prism enclose an angle of 91° 58′, and they are each inclined to the basal plane *c* at 90° 8′. The solid bounded by the four faces of the prism and the two faces of the basal pinacoid thus approximates to a cube. The cleavage, being parallel to *m* and *c*, is also apparently cubic; but that parallel to *c* is

rather better developed than those parallel to the two *m* faces. The small triangular faces truncating the corners belong to two ortho-domes (*o* and *k*) and to a brachy-dome (*r*).

A large deposit of cryolite occurs in granite or gneiss at Ivigtut in west Greenland. The mineral has probably been deposited by the vapours and hot solutions that emanated from the erupted mass of granitic rock. Large blocks of the material are rarely pure, but contain 10—30 per cent. of admixed impurities, mainly chalybite, but also zinc-blende, galena, copper-pyrites, cassiterite, and other minerals. This deposit, measuring 500 feet in length by 100 feet in width, is quarried, and the cryolite exported to Europe and the United States. The production in the year 1897 amounted to 13,361 tons, and in 1908 to 5,740 tons.

All the constituents of cryolite are utilized in one way or another. The mineral is employed for the manufacture of soda and of metallic aluminium (p. 222). It is also used for the preparation of pure hydrofluoric acid, and in the manufacture of opaline glass and of enamels on iron.

Minerals of the Calcite and Aragonite Groups.

The minerals of these groups are carbonates, that is, combinations of carbon dioxide, or carbonic acid, with a metal; and the latter is here either calcium or some other related element. The members of the two groups differ from one another in their crystalline form, those of one group being rhombohedral and those of the other rhombic. The types of each group consist of calcium carbonate, which is therefore dimorphous, crystallizing in the rhombohedral system as calcite, and in the rhombic system as aragonite. The members within each of these groups are closely related to one another in crystalline form and are analogous in chemical composition, in other words, they are isomorphous.

Calcite possesses perfect cleavages parallel to the faces of the primary rhombohedron, and any piece of calcite when struck with a hammer separates into rhombohedral fragments. The same kind of cleavage is possessed by all the other members of this group, and the cleavage fragments differ only slightly, in the several instances, in the angles between their surfaces. The members of the aragonite group, on the other hand, possess no cleavage; but here we find throughout the group a characteristic mode of twinning. By the repeated twinning of these rhombic crystals there are built up hexagonal forms which simulate the rhombohedral forms of the calcite group.

The several members of these two groups are tabulated below, giving the name of the mineral and its chemical composition; and also, for the calcite group, the angle of the cleavage rhombohedron *R*, and, in the aragonite group, the angle of the vertical prism ∞P. We see that in the calcite group the place of calcium may be taken by the related elements magnesium, iron, manganese, or zinc; whilst in the aragonite group calcium may be replaced by barium, strontium, or lead.

Calcite Group.
(Rhombohedral).

Mineral.	Formula.	*R*.
Calcite	$CaCO_3$	105° 5′
Magnesite	$MgCO_3$	107° 20′
Chalybite	$FeCO_3$	107° 0′
Rhodochrosite	$MnCO_3$	107° 0′
Calamine	$ZnCO_3$	107° 40′
Dolomite	$CaCO_3 . MgCO_3$	106° 20′
Ankerite	$CaCO_3 . FeCO_3$	106° 10′

Aragonite Group.
(Rhombic).

Mineral.	Formula.	∞P.
Aragonite	$CaCO_3$	116° 10′
Witherite	$BaCO_3$	117° 48′
Strontianite	$SrCO_3$	117° 18′
Cerussite	$PbCO_3$	117° 14′
Alstonite	$(Ca,Ba)CO_3$	

Some of these minerals have been already considered, namely, chalybite (p. 158), rhodochrosite (p. 170), calamine (p. 130), and cerussite (p. 120). The remaining important members to be now dealt with are calcite, magnesite, and dolomite of the calcite group, and aragonite, witherite, and strontianite of the aragonite group.

Minerals of the Calcite Group.

Calcite is a mineral of extremely wide distribution, and in its crystalline form and physical characters it presents many points of interest; further, by reason of its chemical composition, it has many economic applications of the first importance.

In its *crystalline form* calcite affords the best example of the rhombohedral system. In no other mineral do we meet with such an extensive variety of forms and combinations. The shapes of the crystals are indeed so varied, and frequently so complex, that were it not for the perfect rhombohedral cleavage to act as a guide it would not always be easy to interpret their forms correctly. The cleavage rhombohedron is taken as the primary rhombohedron with the Naumannian symbol $+ R$, and the angles between its faces (arbitrarily lettered p in text-fig. 249) are 105°5′ and 74°55′. A rough classification of the numberless shapes of calcite crystals may be made according to the predominance of certain forms. Thus we may have crystals of rhombohedral, scalenohedral, prismatic, or tabular habit.

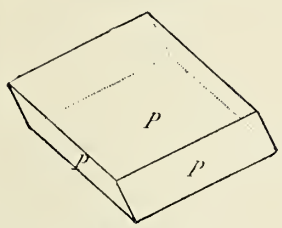

Fig. 249.
Crystal of Calcite: primary rhombohedron.

Fig. 250.
Crystal of Calcite: obtuse negative rhombohedron.

Amongst crystals showing a *rhombohedral habit* we have first those consisting simply of the primary rhombohedron (plate 72, fig. 5), in which the form is identical with the cleavage rhombohedron (plate 73, fig. 8). This rhombohedron is described as a positive rhombohedron, and all other rhombohedra which have their faces sloping in the same direction are also regarded as positive; other rhombohedra in which the slope is in another intermediate direction are called negative. The most commonly occurring form on calcite is the obtuse negative rhombohedron $-\frac{1}{2}R$ (text-fig. 250), with an angle of 135° between its faces. This is derived from the primary rhombohedron by truncating the three pairs of upper and lower edges of the latter form: its faces slope in the same direction as the edges of the primary rhombohedron, as may be seen from a comparison of text-figs. 249 and 250. This form is shown alone in plate 72, fig. 1, and in combination with the hexagonal prism of the first order in figs. 3 and 6; in fig. 3 the prism is short, while in fig. 6 (and text-fig. 251) it is much longer. The Naumannian symbol for this combination is $-\frac{1}{2}R, \infty R$.

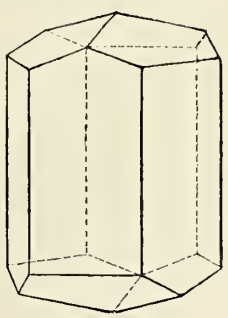

Fig. 251.
Crystal of Calcite: combination of obtuse negative rhombohedron and hexagonal prism.

Another rhombohedron of frequent occurrence is the acute negative rhombohedron with the symbol -2 R, and an angle of 78°50′ between its faces (plate 72, figs. 4 and 8; and text-fig. 252). The edges of this form are truncated by the faces of the primary rhombohedron (compare text-figs. 249 and 252). Many more rhombohedra, in all about seventy-five, have been observed on the mineral calcite. A combination of two rhombohedra is represented in plate 72, fig. 2; here the narrow faces of the form $-\frac{1}{2}$ R truncate the edges of the form $+$ R.

Crystals of *scalenohedral habit* are of frequent occurrence. The commonest scalenohedron is that with the symbol R 3, represented as a simple crystal in plate 73, fig. 3, and text-fig. 253: here there are two sets of angles over the edges which meet at the top and the bottom of the crystal, three being more acute (104° 38′) and the alternate three more obtuse (144° 24′). The same form is shown in combination with the hexagonal prism ∞ R in fig. 2; and with this prism and the obtuse rhombohedron $-\frac{1}{2}$ R in fig. 1. The large crystal in fig. 4 is a combination of the scalenohedron R 3 and the obtuse rhombohedron $-\frac{1}{2}$ R, and below it is bounded by large cleavage surfaces. In all about 187 different scalenohedra have been observed on calcite.

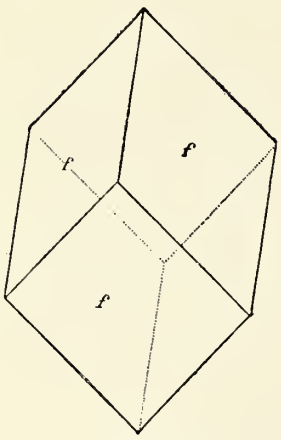

Fig. 252.
Crystal of Calcite: acute negative rhombohedron.

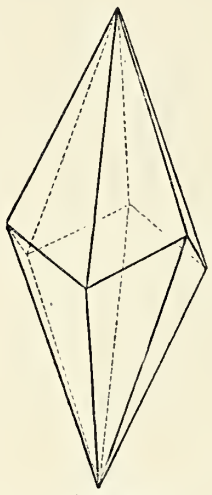

Fig. 253.
Crystal of Calcite: scalenohedron.

On crystals of a *prismatic habit* the hexagonal prism is generally that of the first order. Such a form cannot of course exist alone, unless the ends of the crystal are broken. It is shown in combination in plate 72, fig. 6, and plate 73, fig. 2, and with the basal plane in plate 2, fig. 6. Calcite crystals of the form last mentioned are sometimes called "cannon-spar".

In crystals of *tabular habit* we have a preponderating development of the basal plane 0 *P*. Plate 72, fig. 7, shows this form in combination with a short hexagonal prism ∞ P. Sometimes such crystals are extremely thin, like wafers, when the popular name "paper-spar" is applied.

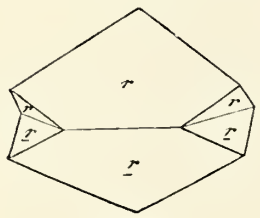

Fig. 254.
Twinned crystal of Calcite: rhombohedron twinned on the base.

Twinned crystals of calcite are also of frequent occurrence, and there are several types of twinning. The primary rhombohedron twinned on the basal plane is shown in text-fig. 254, and the cleavage form of such a twin in plate 73, fig. 9; when the re-entrant angles are not developed (as in fig. 9) such a form is a double triangular pyramid. When the scalenohedron is twinned on the base, the zig-zag edges at the side of the crystal are replaced by horizontal edges, and on three of the corners there are re-entrant angles each formed by a group of four small faces (plate 73, fig. 6, and text-fig. 255).

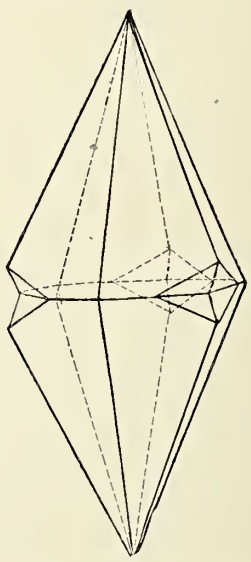

Fig. 255.
Twinned crystal of Calcite: scalenohedron twinned on the base.

Crystals twinned on the primary rhombohedron + R are represented in text-fig. 256 and in plate 73, fig. 5. In the former, showing a cleavage fragment, we see distinctly the twin junction running through the middle and parallel to the cleavages at the top and bottom. Such a twin combination may be exactly imitated by placing two cleavage rhombohedra of calcite one over the other in reversed positions. In fig. 5 is shown one of the beautiful "heart-shaped" twins from the Cumberland iron mines; and similar crystals, but more compressed in form, the so-called "butterfly-twins",

are common from Derbyshire. In this figure the twin-plane is set vertically, and there are to be seen indications of the cleavage parallel to this direction: the vertical axes of the two individuals are inclined on either side, and make with one another an angle of approximately 90° (actually 90° 46′).

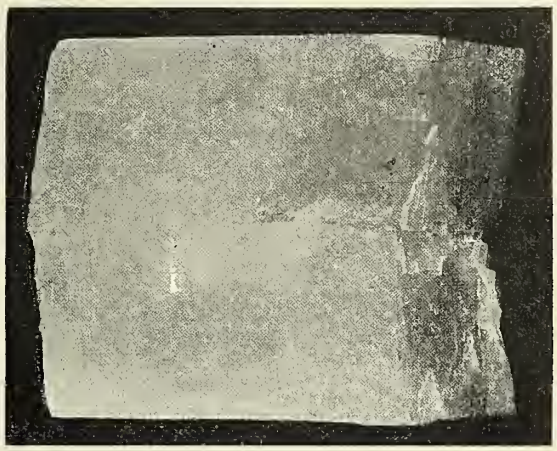

Fig. 256.
Twinned cleavage of Calcite : twin-plane + *R*.

Twinning on the obtuse negative rhombohedron $-\frac{1}{2}$ R is shown by the cleavage fragment in plate 73, fig. 7. Here the lower shaded portion is in twinned position with respect to the upper portion, and a re-entrant angle is shown to the right: the twin-plane and face of union of the two portions runs parallel to the face of $-\frac{1}{2}$ R that would truncate the uppermost edge of the figure. This is the commonest of the twin-laws of calcite, but only exceptionally is it represented by completely developed twinned crystals with two distinct individuals. Most frequently the twinning is often repeated, giving rise to a lamellar structure or twin-lamination in the crystal. This produces the striations often to be seen on cleavage surfaces of calcite, these striations being parallel to the longer diagonal of the rhomb-shaped faces of the cleavage form. In plate 73, fig. 8, we see colourless lamellae running in this direction through a yellow rhombohedron.

Still another type of twinning is that in which the twin-plane is the acute negative rhombohedron — 2 R, but this is of rare occurrence.

The common type of twinning on the obtuse negative rhombohedron $-\frac{1}{2}$ R is related to the existence in calcite of a *glide-plane* parallel to this direction. We have already seen that cleavage cubes of rock-salt may be separated by pressure along a plane of gliding (p. 348), but in calcite translation along the glide-plane gives rise to secondary twinning. If a knife be gently pressed into a polar edge (i.e. one of the three edges meeting in the apex of fig. 249) of a cleavage fragment of Iceland-spar, it will be found that the material gives almost like cheese, slipping away towards the apex in the direction of the arrow (text-fig. 257). The displaced portion now shows an acute solid angle where formerly there was an obtuse solid angle, and a re-entrant angle has been developed on the face at the side. As shown in the text-figure this displaced portion is in twinned position with respect to the main fragment. The glide-plane, which at the same time is the twin-plane, is seen from the figure to be parallel to a plane which truncates the edge of the primary rhombohedron, being in fact a face of the obtuse negative rhombohedron $-\frac{1}{2}$ R.

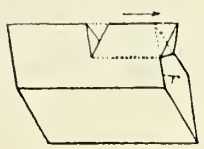

Fig. 257.
Calcite showing twinning artificially produced along the glide-plane $-\frac{1}{2}$ *R*.

Such secondary twinning is also produced naturally in calcite as a result of movements in the earth's crust; and the twin shown in plate 73, fig. 7, has no doubt been formed in this way. Calcite showing lamellar twinning (plate 73, fig. 8) is frequently met with in mountainous districts where earth pressures have operated. Twin-lamellae of the same kind may be induced in a thin cleavage flake of calcite by the following method: the flake is placed on an elastic cushion and pressed gently with the blunt edge of a chisel applied in the direction

of the longer diagonal of the rhomb face. Along each line that the pressure is so applied a twin-lamella is developed without the plate being broken.

Of the *physical characters* of calcite the most striking and remarkable is the very strong double refraction, of which mention has already been made (p. 58; plate 3a). The index of refraction of the ordinary ray is 1·6585 and of the extraordinary ray 1·4863 (for sodium-light). By reason of this very strong double refraction the perfectly clear and colourless calcite from Iceland (Iceland-spar) is more suited than any other material for the construction of polarizing prisms (nicol prisms and dichroscopes) and for other optical purposes. Unfortunately, however, the production cannot keep pace with the demand, and consequently the price of such material is continually rising. In the year 1900 material of the best quality sold for £12 per kilogram, and the total production of the quarry in Iceland amounted to only £280.

A plate of calcite cut perpendicularly to the vertical crystallographic axis gives in convergent polarized light a uniaxial interference-figure (plate 4, fig. 1). When viewed in white light the rings are brilliantly coloured, providing the plate is not too thick: a thickness of a quarter of a millimetre gives the best result.

In the degree of transparency of crystals of calcite there may be a wide range. The material is itself without colour, and in fact most crystals are colourless. The yellow colour of the crystals in plate 72, fig. 6, is due to a thin surface film of iron hydroxide, and that of plate 73, figs. 4 and 6, is perhaps also due to the same foreign colouring material. The blackish colour of the crystals in plate 72, fig. 1, is due to an intermixture of earthy manganese oxide; and red crystals (plate 3, fig. 11) are coloured by iron oxide. The enclosure of foreign materials in crystals of calcite is well illustrated by the well-known specimens from Fontainebleau near Paris (plate 72, fig. 8), which sometimes contain as much as 60 per cent. of quartz sand. This has been erroneously called crystallized sandstone; but it is only the calcite that is crystallized and the sand accidentally caught up in this as a mechanical intermixture.

In the mineralogist's scale of hardness calcite is chosen as No. 3. This choice, although convenient, is not a good one, since there is an appreciable difference in the degree of hardness according to the direction in which the test is made. On a cleavage face in the direction of the shorter diagonal (plate 73, fig. 8) the hardness is greater when we scratch downwards from the top of the crystal than when we scratch in the reverse direction along the same line. A piece of calcite will produce a scratch in the upward direction, but not in the downward direction. The specific gravity of calcite is 2·72, and this affords one means of distinguishing calcite from the heavier aragonite.

As we have already seen, calcite consists chemically of calcium carbonate, containing when pure 56 per cent. of lime (CaO) and 44 per cent. of carbon dioxide (CO_2). Sometimes, however, a small proportion of the lime may be replaced by magnesia, ferrous oxide, or manganous oxide. When calcite is strongly heated its carbon dioxide is expelled and lime remains. This is the well-known quicklime which greedily absorbs water with the development of a considerable amount of heat; and the slacked lime absorbs carbon dioxide from the air with the formation again of calcium carbonate, passing gradually into a hard stony mass. Calcite dissolves readily in cold dilute acetic acid or hydrochloric acid, with a brisk effervescence owing to the escaping carbon dioxide. The solution imparts a yellowish-red colour to the Bunsen-flame. Calcite is appreciably attacked by water containing carbon dioxide in solution.

Origin. — The solubility of calcium carbonate in water charged with carbon dioxide is a factor of considerable importance in nature. Rain water absorbs carbon dioxide from the atmosphere and from the soil, and penetrating into the rocks at the earth's surface it

is thus capable of taking up calcium carbonate in solution. When the carbon dioxide escapes from the solution the calcium carbonate is deposited and then frequently acquires a crystallized form. In this manner beautiful crystals of calcite have been formed in the cavities of limestone rocks (text-fig. 2, p. 6).

In the same way, also, are formed the wonderful stalactitic growths of calcite in limestone caverns. Carbonated waters percolating through the crevices in the limestone rocks take up calcium carbonate in solution, and by so dissolving the rock the crevices are at the same time enlarged with the formation of underground water-courses and caverns. When the water so charged drips from the roof of such a cavern it loses some of its dissolved carbon dioxide, and the calcium carbonate consequently falls out of solution. This process

Fig. 258.
Stalactites and Stalagmites in the Dechen Cave at Letmathe, Westphalia.

continued for a long period of time gives rise to a rod of calcite — known as a *stalactite* — suspended from the roof of the cavern. While falling, the drops of water lose still more carbon dioxide, and there is thus formed on the floor of the cavern an upward-growing *stalagmite*. With the slow but continued growth of the stalactite downwards and of the stalagmite upwards the two at last meet forming a column extending from the floor to the roof of the cavern. All manner of fantastic forms, with resemblances to organ-pipes, heavy curtains, etc., are formed by this constant dripping of water in limestone caverns. Text-fig. 258 gives a view of the Alhambra grotto in the Dechen Cave (so named after a German geologist) at Letmathe in Westphalia. The limestone caves of certain districts are far-famed, for example, those at Rübeland in the Harz Mountains, in the limestone districts of Derbyshire and Yorkshire, the Adelsberg Cave in Carinthia, the Jenolan Caves in New South Wales, and the Mammoth Cave of Kentucky; the last named, probably the largest of all, extending for a distance of 240 kilometres (144 miles).

Under other conditions the carbon dioxide may be extracted from the charged waters by living plants; the calcium carbonate is then deposited around the plants and takes their form, giving rise to porous masses of calcareous *tufa* or calcareous sinter. The *travertine* of Tivoli, which formed the principal building stone of ancient Rome, is of this nature.

The waters of all rivers contain calcium carbonate in solution, and enormous quantities are thus carried to the ocean. Here the solution is so dilute that there can be no direct precipitation of calcium carbonate. Nevertheless, practically the whole of the limestone rocks which form part of the solid crust of the earth have been deposited in the sea. Calcium carbonate is extracted from sea-water by various organisms for the formation of their hard parts, such as shells and coral skeletons. Accumulations of these give rise to the formation of beds of *limestone*, for example, shell-limestone, coral-limestone, crinoidal limestone, nummulitic limestone, etc. The common *chalk* is also of the same nature, being formed largely of the minute shells of foraminifera. Of the many other varieties of limestone rocks, mention may also be made of the very fine-grained and compact *lithographic stone* quarried at Solenhofen in Bavaria, which is extensively used in printing: all the coloured plates in this volume have, for instance, been printed from lithographic stones. Another form of limestone is that known as *oolite* or roe-stone, which consists of a close aggregate of tiny spheres like the roe of a fish.

All these various forms of limestone are more or less compact and close grained in texture. They are of wide distribution, and it is not necessary in this place to enter into any further description, nor to mention occurrences at particular localities. In some the texture is sufficiently compact to allow the material to take a fine polish, and we then have a rock which is popularly known as a *marble*. Here with the various enclosed fossils and the intermixed colouring materials we have an endless variety. The mineralogist and petrologist, however, limit the term marble to a crystalline limestone. Here the material of the compact forms of limestone has been re-crystallized by metamorphic agencies acting within the earth's crust. Such a change may be brought about by pressure, or by a baking action and the action of hot solutions in contact with an intruded mass of igneous rock. Crystalline limestones formed by contact-metamorphism are often of a peculiar and light shade of blue (plate 47, fig. 8), and they are characterized by the presence in them of certain minerals, such as garnet, idocrase, wollastonite, etc. When more pure, containing only occasional quartz crystals (plate 54, fig. 11), such crystalline limestones are of importance as statuary marbles.

Crystals of calcite are of common occurrence in the cavities and crevices of limestone rocks. Here the limestone has supplied the material for the growth of the crystals. There are, however, many other ways in which calcite crystals have been formed in nature. By the weathering of lime-bearing silicates, particularly the felspars, calcium carbonate may result and be deposited as brilliant crystals in the cavities of volcanic rocks. In metalliferous veins calcite is rarely absent, and here indeed we find the largest and the finest crystals. A peculiar formation is that of crystals in loose sand, the sand being cemented by the crystallized calcite (plate 72, fig. 8).

The *artificial production* of calcite crystals from calcium carbonate is not a difficult matter. A wet precipitate of calcium carbonate, obtained by adding ammonium carbonate to a solution of a calcium salt, is allowed to stand for some time exposed to the air. Carbon dioxide is absorbed, causing the calcium carbonate to go into solution, when it is re-deposited in a crystalline form In this way microscopic rhombohedra slowly grow in the amorphous mass until the whole becomes crystalline. It is well known to chemists that freshly precipitated calcium carbonate partly passes through a filter-paper giving a

turbid filtrate; but if the precipitate be allowed to stand for a day, a clear filtrate can be then obtained. The explanation of this is that the finely-divided amorphous particles are transformed into larger crystalline grains. We have here an example of the fact that when crystals are growing together under certain conditions, the larger ones grow at the expense of the smaller — in the mineral kingdom, just as in the animal kingdom, the larger devour the smaller.

Another method of growing crystals of calcite is to pass a current of carbon dioxide gas through water containing freshly precipitated calcium carbonate: after a little time the liquid is filtered, and the clear solution allowed to stand in contact with the air. With the gradual evaporation of the solution and loss of carbon dioxide, crystals of calcite are deposited. These crystals are, however, as also in the last experiment, only of microscopic dimensions. This method has been employed in order to determine the conditions under which calcium carbonate crystallizes as calcite or as aragonite. It has been found that form a pure and cold solution the product is mainly calcite; whilst from a hot solution, and especially in the presence of lead or strontium salts, aragonite is deposited.

Still another method is that devised long ago by Sir James Hall (1761—1832), who was the first investigator to attack the problems of geology by the experimental method. He enclosed chalk in a closed gun-barrel, and heated it to a high temperature in a furnace. Owing to the evolution of carbon dioxide from the chalk, the pressure inside the barrel must have been very considerable. After slowly cooling it was found that the amorphous calcium carbonate had become crystalline throughout and converted into marble.

Crystalline limestones must have been formed in nature by some such process as this, for when beds of compact limestone are deeply buried in the earth's crust they would be subjected to heat and pressure. The presence of water and carbon dioxide also no doubt aided the crystallization of the material.

The simple *weathering* of limestone does not take place by reason of any chemical alteration or destruction of the material, but rather by reason of its solubility in water charged with carbon dioxide. The rocks are simply dissolved, and their surfaces present a corroded aspect.

The case is different, however, when waters containing metallic salts in solution come into contact with limestone or calcite. Here we have extensive chemical replacements, as amply testified by the many kinds of pseudomorphs after calcite which we find in nature. The pseudomorph after calcite shown in plate 3, fig. 12, has already been discussed in some detail on p. 50. Pseudomorphs of pyrolusite, dolomite, and calamine after calcite are also of common occurrence.

By a similar metasomatic replacement of beds of limestone there may be formed extensive deposits of iron, manganese, and zinc ores, as already explained in the case of zinc (p. 130). To give another example, we may mention that of the alteration of limestone in the Schmalkalden mining district in Prussia. Here springs of chalybeate waters rising through crevices in the limestone rocks have transformed the latter into chalybite and limonite. In all these cases we have a replacement of a more readily soluble mineral by one that is less soluble.

The *localities* at which fine crystals of calcite are found are very numerous, and here only a few of the more important can be mentioned. In crevices in *limestone*, crystals are found at Bieber in Hesse (plate 72, fig. 1), Iserlohn in Westphalia (plate 3, fig. 10), etc. Cavities in contact-marble at Auerbach in Hesse contain large twinned crystals (plate 73, figs. 7—9, and text-fig. 256). In *volcanic rocks*, the agate-lined cavities of the Nahe district in Germany contain crystals of calcite, and fine crystals are found in the copper mines of Lake Superior in North America. The noted Iceland-spar occurs filling a large cavity in

basalt close to the farm Helgustadir, near Eskifjördur on the Reydar Fjördur, east coast of Iceland. Occurrences in *metalliferous veins* are especially abundant; for example, at Andreasberg in the Harz (plate 2, fig. 6; plate 72, figs. 2, 4, and 7), Freiberg in Saxony (plate 72, figs. 3), Cornwall, Devonshire, and Derbyshire (plate 73, fig. 6), Joplin in Missouri (plate 73, fig. 4), Guanajuato in Mexico (plate 73, fig. 3), etc. Deposits of *iron ores* frequently yield good crystals; the haematite mines in the neighbourhood of Egremont in west Cumberland produce magnificent crystals and groups in almost superfluous quantities (plate 73, figs. 1 and 3). A similar occurrence in red-iron-ore is also met with at Oberscheld near Dillenburg in Nassau (plate 72, fig. 6). Good calcites are also found in the *crystal-lined crevices* traversing the gneissic rocks of the Alps; and a similar occurrence is that at Poretta near Bologna in the Apennines (plate 72, fig. 5). Crystals are found in loose *sand* at Fontainebleau near Paris (plate 72, fig. 8), at Dürkheim in Rhenish Bavaria, Sievring near Vienna, and in the Bad Lands of Washington Co., South Dakota.

Applications of calcite, limestone, and marble.—The use of clear crystallized calcite for the construction of polarizing prisms has already been mentioned above more than once. The varied applications of limestones depend, on the one hand, on their texture, and, on the other, on their chemical composition. The extremely fine grained and homogeneous limestone of Solenhofen in Bavaria is used as a lithographic stone. Other limestones are used extensively for building purposes, for example, the Roman travertine, the English Portland and Bath stones, and many others of importance. When compact enough to take a polish limestones are much used as ornamental stones for inside decoration. The softer chalk is used as a writing material, for polishing, and many other purposes.

Enormous quantities of limestone are quarried to be burnt in kilns for lime and for the manufacture of cement. A pure limestone yields when burnt a "fat" or white lime which is readily slacked; whilst the "poor" lime given by an impure limestone slakes only with difficulty. Cements manufactured from limestone include hydraulic cement, in which the lime is combined with free silica, and the important Portland cement. The latter is made from a clayey limestone or from limestone and clay intimately intermixed in the proper proportions by artificial means; this is burnt in kilns of a special type until the mass sinters; the clinkers are then ground to a fine powder, and this when mixed with water sets to a hard mass. Portland cement contains: lime (CaO) 55—66, silica (SiO_2) 19—26, alumina (Al_2O_3) 4—10, iron oxide (Fe_2O_3) 2—4 per cent., together with small amounts of magnesia, alkalis, sulphuric acid, carbonic acid, and water. In the year 1901 the production of Portland cement in 85 works in Germany amounted to $3^1/_3$ million tons; but since that date far larger quantities are produced, in that and other countries, owing to the extensive employment of concrete for building purposes.

In the smelting of iron ores the addition of limestone is necessary for the formation of the slag, the lime combining with the silica and phosphorus of the ore (p. 160). Lime is used for the manufacture of glass (p. 273); when mixed in water for white-washing; mixed with various metallic oxides, it is used in the manufacture of colours (p. 114). In the chemical industries, limestone is used in the manufacture of soda (p. 357) and bleaching powder. The latter is a calcium salt consisting of a mixture or combination of chloride and hypochlorite, $CaCl_2 + Ca(OCl)_2$, which is readily decomposed by the weakest acids with the evolution of chlorine; and being easily transported and handled it contains the chlorine in a readily available form for bleaching and disinfecting purposes. Another important product, namely calcium carbide (CaC_2), is manufactured by heating a mixture of limestone and coal in the electric furnace; this when decomposed by contact with water gives a supply of acetylene gas, which is now much used for illuminating. These examples serve to indicate the extremely important rôle that limestone plays in the industries and in technical processes.

The *occurrence of marble*, presenting many points of interest, may be briefly dealt with in this place. The most important deposits are those in Greece and Italy, and it was these that supplied the material for the famous sculptures of the ancients.

The largest deposit is that in the neighbourhood of Carrara in Tuscany; it reaches a thickness of 1000 metres, and extends over a wide area in the Apennines. Here, as a result of the pressures accompanying mountain building, the limestones of Triassic age have become crystalline and converted into marble. At the present day Carrara is the most important marble-producing district in the world; together with the neighbouring districts of Massa and Seravezza, the annual yield is about 70,000 cubic metres, of the value of £ 800,000 to a million pounds. The best quality, the "statuario" or statuary marble, is snow-white with a fine saccharoidal texture, and a slight shimmer and translucency on the surface. Such material amounts to only about 5 per cent. of the whole production; the remainder is sawn into slabs for use as table-tops, window-sills, etc. (and, curiously, is used under the trade-name of "Sicilian" marble).

The famous Greek statuary marbles came mainly from the adjoining mountains of Pentelicus and Hymettus in Attica, and from the islands of Paros and Naxos. According to R. Lepsius*) there are twenty-five ancient marble quarries to be seen on Mt. Pentelicus, from which at a moderate estimate 400,000 cubic metres of marble have been taken. This large quantity of material was used, not only for the famous buildings (Parthenon, Erechtheum, Propylaea, Theseum, Olympieum) of Athens, but also in other parts of ancient Greece and in Rome. Almost every museum in modern Europe contains examples of statuary executed in this antique Pentelic marble. Several large buildings in London have recently been constructed of this material. It is snow-white with a tinge of yellow, and a fine-grained crystalline texture rather like that of beet-sugar. This stone possesses the peculiarity that the small grains of calcite are set in a very fine-grained to compact groundmass which is milk-white and translucent.

Such a compact groundmass is not seen in the marbles of Paros and Naxos, in which the grain is much coarser. In the Parian marble the grains seldom exceed 3 mm. across, whilst in that from Naxos they reach 10 mm. The most important quarries in ancient times on the island of Naxos were worked underground, and, as lamps were used, the stone was known as *lychnites lithos* or lamp-stone. This is snow-white and very pure, and owing to the coarseness of the grain the light is able to penetrate beneath the surface as in no other marble. The beautiful statue of Hermes of Praxiteles in Olympia is carved in the best Parian marble, and the soft shimmer seen on the surface is due to this transparency of the grains of calcite of which the stone is composed.

Marbles are also of wide distribution in the Alps. The best is the Laas statuary marble from the Vintschgau in Tyrol; this is white and compact with a slightly larger grain than the "statuario" of Carrara. In Germany, marble occurs at Wunsiedel in the Fichtelgebirge, Gross-Kunzendorf in Silesia, and Auerbach in Hesse; but none of these are of statuary quality. Variegated marbles, often rich in fossils, are quarried on the Lower Lahn. Marbles of a similar character are also worked in Devonshire and Derbyshire. The so-called "petit granit" of Belgium is black marble marked with numerous fossils: about 12,000 cubic metres are quarried per annum, of the value of 2—3 million francs. A white marble has recently been worked in Norway. Lastly, there are numerous marble occurrences in the United States; but Carrara marble is imported for the best work.

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*) R. Lepsius, 'Griechische Marmorstudien' (Abhandlungen der Akademie der Wissenschaften, Berlin, 1890).

The so-called *onyx-marble* (Algerian onyx, Mexican onyx, and "oriental alabaster") also consists of calcite in a finely granular or fibrous form. It is distinguished by its high degree of translucency; and with its bands and cloudy patches of different colours it has a pretty effect. Material of this nature has not been formed by the re-crystallization of a limestone rock, but it has been deposited directly from solution in much the same way as stalagmitic calcite. Onyx-marble is frequently cut and polished for small ornamental objects or as larger decorative slabs.

Magnesite. Calcite we have dealt with above at some length, but the other members of this group will occupy much less of our time, for they show less variety of form and their applications are limited. Whilst in calcite the primary rhombohedron is comparatively rare as a simple form, in the other members of the group this form is of common occurrence, and in magnesite it is practically the only one met with. Crystals of magnesite are never of large size and they are only found embedded in the matrix; plate 75, fig. 8, shows a dark-coloured rhombohedron embedded in chlorite-schist (the piece of rock being trimmed square). The crystals are sometimes colourless, but mostly yellow or brown, owing to a partial replacement of magnesium carbonate by iron or manganese carbonate. The hardness (H. = 4—$4^1/_2$) and specific gravity (2·9—3·1) are higher than for calcite.

Crystals of magnesite are found embedded in chlorite-schist and talc-schist in the Swiss and Tyrolese Alps (for example, in the Pfitsch and Ziller valleys); and in serpentine at Snarum in Norway. Black, compact masses are found in gypsum at Hall in Tyrol. More usually, the mineral is met with as fissured nodules of snow-white colour and compact texture. Such material is often impregnated with silica, and it occurs in connexion with serpentine as a product of the weathering of olivine-rocks. Localities are: Frankenstein in Prussian Silesia, Kaiserstuhl in Baden, Kraubat in Styria, and Hrubschitz in Moravia. In the eastern Alps it occurs in considerable quantities and is won by mining. Formerly it was used for the preparation of pure carbon dioxide and of epsom-salts, but now these products are obtained respectively from springs and the Stassfurt salts. At the present day magnesite is largely used for the manufacture of refractory bricks and furnace linings, artificial stone, tiles, etc.

Dolomite. The two compounds which we have considered under calcite and magnesite enter into combination to form the double salt $CaCO_3 . MgCO_3$, which expresses the composition of dolomite. Since the two components belong to the same isomorphous group, the question may very naturally be asked, why is this a double salt and not an isomorphous mixture? It is found that pure crystals of dolomite always contain very nearly 54 per cent. of calcium carbonate and 46 per cent. of magnesium carbonate; that is, the two carbonates are present in equal molecular proportions. With isomorphous mixtures, on the other hand, the two components are present in indefinite and variable proportions. In some varieties of dolomite, to which the name brown-spar is loosely applied, a portion of the magnesium is replaced by iron and manganese; and in these instances the double salt relation is expressed in the ratio of $(MgO + FeO + MnO) : CaO = 1 : 1$.

Chemically, therefore, dolomite is clearly a double salt, but this double salt possesses the unusual feature of exhibiting a crystalline form very like those of its component salts. The rhombohedral angle of dolomite (106° 20′) lies, in fact, between the corresponding angles of calcite (105° 5′) and magnesite (107° 20′). But it has been shown by closer examination that the degree symmetry possessed by crystals of dolomite is not the same as in calcite and magnesite. Etched figures and the occasional presence of certain rare faces prove that the symmetry of dolomite is rhombohedral-tetartohedral (p. 36).

The crystals are, as a rule, bounded by only the faces of the primary rhombohedron; and they are sometimes quite large and sharply developed (plate 75, fig. 7). In this figure

we have a twin intergrowth of two (or rather three)*) rhombohedra: being viewed from above, we see the three polar edges which meet in the apex of the crystal. The two crystals are orientated in reverse positions with respect to one another; and if we imagine one crystal to be rotated through 180° about the vertical axis (approximately perpendicular to the paper as represented in the picture), we shall find that it comes into the position of the other crystal. The basal plane (perpendicular to the vertical axis) would therefore, if present, be common to the two individuals of the twin; and this is consequently regarded as the twin-plane.

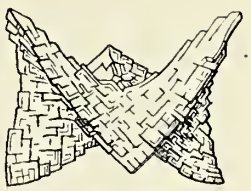

Fig. 259.
Saddle-shaped crystal of Dolomite.

Large and sharply-developed crystals like those just described are, however, of exceptional occurrence. More usually the mineral is observed as small rhombohedral crystals with a saddle-like curvature, and they are closely crowded together on the surface of the matrix (plate 75, fig. 10). This peculiar curvature of the crystals (text-fig. 259) is due to their being built up of a number of smaller individuals arranged next to one another in not quite parallel position, each successive one being removed farther and farther from its true position. A sub-parallel grouping of a similar nature we have already observed in the twisted crystals of smoky-quartz, and the sheaf-like crystals of stilbite. The small, black crystal represented in plate 75, fig. 9, consists of a combination of an acute rhombohedron 4 *R* with the basal plane 0 *R*, the edges between these two forms being truncated by narrow faces of the primary rhombohedron *R*.

Dolomite shows practically no effervescence with cold hydrochloric acid, but it dissolves readily and completely when warmed. This difference in behaviour from calcite affords an easy means of distinguishing the two minerals. Also in carbonated water dolomite is much more difficultly soluble than calcite, and this difference has an important bearing on the formation of the mineral. 10,000 parts of water saturated with carbon dioxide at a temperature of 18° C. dissolves 10—12 parts of calcite, but only 3 parts of dolomite. In its higher hardness of $3^1/_2$—4 and specific gravity of 2·85 — 2·95, dolomite also shows a difference from calcite. The double refraction is here also very strong; but the crystals being usually small and not clear this is not an obvious character. Twin-lamellae, which are so common in calcite, are never seen in dolomite, and there is no glide-plane or plane of secondary twinning.

Colourless, water-clear crystals of dolomite are found in the drusy cavities of the snow-white, saccharoidal dolomite-rock of the Binnenthal in Wallis, Switzerland. Large, yellowish or greyish-yellow crystals (plate 75, fig. 7) occur together with crystals of quartz, iron-pyrites, and mesitite ($2MgCO_3 . FeCO_3$) in the deposits of magnetic iron-ore at Traversella in Piedmont. Small black crystals, coloured by carbonaceous matter, are embedded in gypsum at Hall in Tyrol and Teruel in Spain (plate 75, fig. 8). Yellowish crystals occur together with magnesite embedded in the talc- and chlorite-schists of the Alps: and the two minerals are then so similar in appearance that they are readily mistaken the one for the other. Small, white, grey, or yellowish crystals with curved faces are of frequent occurrence in mineral-veins; for example, at Freiberg in Saxony, Schemnitz in Hungary, Cornwall and Devonshire, Cumberland and Co. Durham, Laxey in the Isle of Man, etc.

In addition to crystals, dolomite occurs abundantly as large masses, forming a rock to which the name dolomite is also applied. Here again the parallel with calcite is complete. Corresponding with marble we have the crystalline saccharoidal dolomite of

*) The third, smaller individual, on the right in the lower part of the picture, is in twinned position with respect to the central individual, and therefore parallel to that on the left.

the Alps. This occurs, for example, in the Binnenthal in Wallis, and is shown in plate 20, fig. 3, as the matrix of crystals of zinc-blende: it also carries a number of rare minerals for which this locality is famous. A very similar rock is met with at Campo longo in Canton Tessin, here forming the matrix of splendid crystals of green tourmaline, and also of red and blue corundum. Corresponding with common limestone we have a compact dolomite rock, which frequently displays a characteristic spongy or cavernous texture. In such rocks, however, there is often less magnesium carbonate than is required by the formula $CaCO_3.MgCO_3$, and they are then more correctly described as magnesian limestones. They are of wide distribution, and are often employed as building stones; the Houses of Parliament in London, for example, being built of magnesian limestone from Bolsover Moor in Derbyshire. In the north of England this rock is of Permian age: that of the Dolomite mountains in southern Tyrol is of Triassic age; and the dolomite of Swabia belongs to the Jurassic formation.

Much has been written on the origin of dolomite rocks. In some instances they have doubtlessly been formed by the weathering of limestones containing a small proportion of magnesium carbonate: by the removal of the more soluble calcium carbonate there has been an enrichment of magnesium carbonate in the cavernous rock which remains behind. Again, solutions carrying magnesium salts when brought into contact with limestone would carry away calcium carbonate and deposit magnesium carbonate, in the same manner that zinc ores are deposited (p. 130). It has been proved by borings in coral islands that the coral-limestone is slowly acted on by the magnesium salts contained in sea-water.

Minerals of the Aragonite Group.

Aragonite is the other and rarer modification of calcium carbonate, but still it is a mineral of importance. A small proportion of the calcium is sometimes isomorphously replaced by strontium or lead; and formerly it was believed that this admixture of strontium constrained the calcium carbonate to crystallize as aragonite rather than as calcite. Now, however, we know that many substances crystallize as different modifications, and calcium carbonate is one of such dimorphous substances. The difference between aragonite and calcite lies mainly in their crystalline form and physical characters, and less markedly in the chemical properties: in their ultimate chemical composition they are identical.

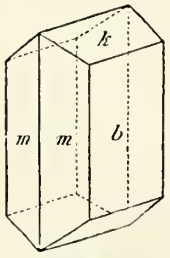

Fig. 260.
Untwinned crystal of Aragonite.

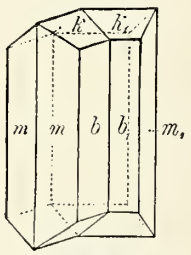

Fig. 261.
Twinned crystal of Aragonite.

Crystals of aragonite when untwinned exhibit a very simple and typical rhombic form: as shown in plate 74, fig. 1, and text-fig. 260, they are bounded by a vertical prism $m = \infty P$, the brachy-pinacoid $b = \infty P \breve{\infty}$, and a brachy-dome $k = P \breve{\infty}$. The angle between the faces of the vertical prism is 116° 10′, and that of the brachy-dome is 108° 26′. Spear-shaped crystals, with faces more steeply inclined, also occur; these usually form columnar aggregates (fig. 12) or small tufts.

Usually, however, the crystals are twinned, the twin-plane being a face of the vertical prism; but owing to differences in the form of the single crystals and the manner in which they are united, the twin-crystals may present very different appearances. In text-fig. 261 we have a simple twin of two individuals of equal size: here in the actual crystals (plate 75, fig. 4) the re-entrant angle formed by the brachy-pinacoid faces b b_1 is usually grown over by the extension of the adjoining prism-faces; so that the twinned crystal

shows a re-entrant angle only at its end between the dome-faces $k\ k_1$. This twinning on one of the prism-faces may be repeated several times (text-fig. 262), the adjacent portions being in twinned position with respect to one another, but alternate layers (first, third, fifth) are in parallel position. In this case the first and last portions are usually larger in size, the intermediate portions being quite thin, as represented in plate 74, figs. 3 and 4. If the first and last portions are in parallel position the crystal may then present the appearance of a simple crystal, and the presence of lamellar twinning is betrayed only by the striations on the surfaces.

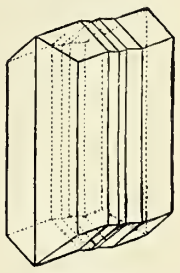

Fig. 262.
Crystal of Aragonite repeatedly twinned on the same prism-face.

In other crystals the twinning takes place on both faces of the rhombic prism; but, curiously, this happens only in crystals that are terminated by the basal plane. When, in these twinned groups, the obtuse angles of the prisms lie towards the centre only three crystals are necessary to almost close the ring, for the prism angle 116° 20′ approximates to a third of the circumference of a circle. The remaining space is sometimes left open, but more usually it is grown over by the material of the adjoining crystals. If, however, the acute angles of the prisms fall in the centre of the group, then six individuals may enter into the ring. There may thus be considerable variation in the manner of grouping, but the result is always an apparent hexagonal prism terminated by the basal plane, as shown in plate 74, figs. 5—8. The twinned crystal in fig. 5 appears to be built up of four individuals, two with their acute prism angles at the centre, and two with their obtuse angles in this position; here the ring is completely closed, for twice 63° 50′ and twice 116° 10′ give 360°.

The exact manner in which the several individuals are joined together cannot always be made out from an inspection of the striations and the areas of different lustre. But this is readily seen when the crystals are examined in parallel polarized light. For this purpose it is necessary to cut a thin plate parallel to the basal plane. The area of extent of each individual is then marked out distinctly, and on rotating the stage of the polariscope one is dark while the others are light. Such a plate when examined in convergent polarized light shows a biaxial interference-figure (plate 4, figs. 3 and 4). Placing the plate in the diagonal position (fig. 4), there is no change in the figure so long as the area of a single individual remains in the field of view, but if the section be shifted so that we pass over a twin-junction the figure suddenly jumps into another position. The double refraction of aragonite is very high, the three principal indices of refraction being, for sodium-light,

$$\alpha = 1{\cdot}5301,\ \beta = 1{\cdot}6816,\ \gamma = 1{\cdot}6859.$$

As represented in plate 74, crystals of aragonite may be white, pale yellowish, wine-yellow, brownish, or reddish to violet. They are sometimes clear and transparent, but more frequently cloudy, and in thicker crystals opaque.

We thus see that there are important differences between calcite and aragonite in their crystalline form and optical characters, in spite of the fact that the latter by its twinning in pseudo-hexagonal forms mimics the former. With distinctly developed crystals the two minerals may be readily distinguished, but with small grains and finely fibrous aggregates this is less easy. Here we must rely on the other physical characters. In aragonite there is an absence of cleavage, its fracture being irregular to sub-conchoidal. Of first importance is the higher specific gravity of 2·93, as against 2·72 of calcite. In pure bromoform aragonite therefore sinks, whilst calcite floats, and this difference in behaviour can be observed with quite tiny grains. Aragonite can be readily distinguished from the

other rhombic carbonates by its flame reaction: when moistened with hydrochloric acid it imparts a yellowish-red colour to the Bunsen-flame.

As in the case of other dimorphous substances, a change of state is brought about by the application of heat, but here the change takes place in one direction only. When heated to a temperature of about 300° C. aragonite passes into calcite, but on cooling the reverse change does not take place. Such dimorphous substances are known as *monotropic*, and of this aragonite affords the best example amongst minerals. When this change takes place the particles of calcite that are developed within the aragonite crystal are orientated in a perfectly definite manner: their vertical axes are all parallel to the vertical axis of the aragonite. The change in state being accompanied by an appreciable increase in volume (corresponding to the difference in specific gravity), the altered crystal is incoherent and readily falls to powder.

This alteration of aragonite to calcite, as well as the conditions necessary for the formation of the two minerals (p. 385), indicate that aragonite is the more unstable form of calcium carbonate; a fact which is also borne out by the weathering of the mineral. Like calcite, aragonite is also readily attacked and dissolved by weathering agents. At the same time it becomes in part altered into calcite; this being possible by reason of the easier solubility of aragonite. A solution of calcium carbonate, which is saturated for aragonite, is capable of depositing calcite, since for this substance such a solution is supersaturated. Aragonite when in contact with carbonated water will thus be slowly converted into the more stable calcite. That such changes have taken place in nature is shown by the occurrence of pseudomorphs of calcite after aragonite (plate 74, fig. 9). Here the external form is the same as in figs. 5—8, but the crystals are hollow, owing to the partial removal of calcium carbonate in solution; and their surfaces are rough and drusy, owing to the secondary growth of calcite. Another pseudomorphous crystal of the same twinned form is shown in fig. 10; here the replacing substance is native copper.

Aragonite also frequently forms fibrous aggregates with a divergent or radial arrangement: a tendency in this direction is shown by the specimen in fig. 12, and more distinctly by that in fig. 11, plate 74. Usually, however, the fibres are extremely fine, and their aggregation gives rise to a variety of external forms. The *pisolite* or pea-stone (fig. 1, plate 75) deposited by the hot springs at Carlsbad in Bohemia consists of a number of small spherical masses, which possess a concentric shelly structure; each shelly layer being built up of fibres of aragonite arranged perpendicularly to the surface. In the curious variety known as *flos-ferri* (plate 74, fig. 2) the fibres radiate from a central axis, producing branching forms of a snow-white colour and somewhat resembling coral in appearance. It receives this name ("flower of iron") because of its occurrence as an efflorescence in certain iron mines, being produced by the weathering of calcareous spathic iron-ore (chalybite).

As to the modes of occurrence of aragonite: it is found embedded in beds of gypsum; in metalliferous veins and in beds of pyrites; in the cavities of volcanic rocks; as a deposit from hot springs; but only rarely together with calcite in the crevices of limestones. It also frequently occurs as a constituent of the univalve and bivalve shells of molluscs, forming the nacreous layer and constituting also the material of pearls.

The fine, wine-yellow crystals shown in plate 74, figs. 1—4, are found in basalt-tuffs at Horschenz, near Bilin in Bohemia. The crystals altered to calcite in fig. 9 are from the basalt-tuff of the Blaue Kuppe, near Eschwege in Hesse. More usually, however, the aragonite found in basalts and basalt-tuffs has the form of delicate spear-like crystals or of radially-fibrous aggregates, as in the specimen in fig. 11 from the Leidenhöfer Kopf near Giessen in Hesse. Crystals embedded in gypsum are found at Bastennes, near Dax in dep. Landes, France (fig. 6), and at Molina in Aragon (fig. 7). Other localities for crystals

of this habit are Herrengrund in Hungary (fig. 8), the sulphur mines near Girgenti in Sicily (fig. 5), Leogang in Salzburg, and in Keuper marl at Klein-Sachsenheim in Württemberg, the last as large crystals partly altered to calcite. Divergent groups of spear-like crystals are found in iron mines at Frizington in Cumberland (fig. 12) and Iberg in the Harz. The flos-ferri variety comes from the iron mines of Eisenerz in Styria (plate 75, fig. 2), and Hüttenberg in Carinthia. Pisolite and banded masses of finely-fibrous "Sprudelstein" are from Carlsbad in Bohemia: here this material is fashioned into small ornamental objects.

Witherite. Crystals of witherite, although belonging to the rhombic system, are always pseudo-hexagonal in form. The complex twinning which we found to be frequently present in aragonite is here never absent. Simple, untwinned crystals are unknown: their form can only be deduced from a study of the twinned crystals. Such an idealized simple crystal is represented in text-fig. 263; where $p = \infty P$ is the unit vertical prism with an angle of $117^3/_4{}^0$, $o = P$ the unit pyramid, $b = \infty P \breve{\infty}$ the brachy-pinacoid, and $q' = 2P\breve{\infty}$ a brachy-dome. When sections taken parallel to the basal plane are examined in parallel and convergent polarized light, we find a division into six sectors in each of which the plane of the optic axes is parallel to the corresponding side of the hexagon. The pseudo-hexagonal crystals are therefore here bounded by the brachy-pinacoids (or brachy-domes); thus differing from aragonite, in which the exterior of the twinned groups is formed by the faces of the unit prism. The pseudo-hexagonal witherite twins may be regarded either as composed of six individuals meeting in the centre, or of three individuals which overlap and interlock with one another across the centre.

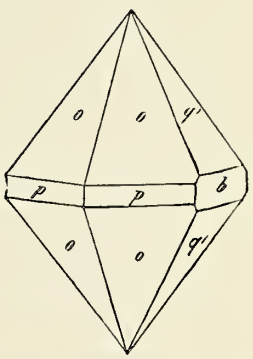

Fig. 263.
Idealized simple crystal of Witherite.

These pseudo-hexagonal crystals vary considerably in their habit. Usually, as shown in plate 75, figs. 3—5, the habit is pyramidal, and the crystals are often terminated at both ends. Or again, the habit may be prismatic with a longer or shorter development of the pseudo-hexagonal prism, which may be combined with either the pyramid or the basal plane or with both. Lastly, when the basal plane is largely developed, the habit may be tabular. The basal plane often shows a flat dome-like curvature, and the crystals of tabular habit may be quite lenticular in shape. The faces of the pseudo-prism and of the pseudo-pyramid are always striated horizontally, just like the prism faces of quartz. There is in fact a striking resemblance in general appearance between the bipyramidal crystals of witherite and certain crystals of quartz, as may be seen from a comparison of the pictures on plates 52 and 75. The great difference in specific gravity, however, at once distinguishes these two minerals.

Witherite also occurs as coarse fibrous aggregates, which frequently show a globular surface, and as granular to compact masses. It is white, grey, pale yellowish or sometimes pale greenish, never exhibiting an intense coloration. The larger crystals are usually cloudy and opaque, but small crystals are occasionally clear and transparent. The hardness is slightly greater than that of calcite, but the specific gravity, 4·3, is far higher. When pure, witherite contains: baryta (BaO) 77·7, and carbon dioxide (CO_2) 22·3 per cent. The mineral is readily soluble with effervescence in dilute hydrochloric acid, and the solution imparts a persistent pale green colour to the Bunsen-flame. This characteristic flame-coloration affords a simple means of recognizing the mineral.

Witherite occurs in some abundance in veins of lead-ore at certain places in the north of England and on the borders of Shropshire and Montgomeryshire. It is sometimes found in association with coal, and near the city of Durham a large vein of barytes and

witherite intersects the coal-measures. The best crystals are from the Fallowfield mine near Hexham in Northumberland, which at different periods has been worked for lead, coal, and witherite. The largest quantities (about 10,000 tons per annum) are mined in the Settlingstones mine in the same district. At a few other localities, for example, Leogang in Salzburg, and Przibram in Bohemia, the mineral is found only in quite small amount.

Although of much less abundance than barytes, witherite is next to this the most important mineral containing barium, and it possesses the advantage for technical purposes of being readily soluble in acid. It is therefore the most important raw product for the preparation of barium compounds. Barium chloride is used as a reagent for detecting the presence of sulphuric acid; the nitrate for producing the green light of fireworks; and the hydroxide is employed in the refining of beet-sugar. Witherite is also employed in the manufacture of plate-glass, and for making rat-poison. For the latter purpose the powdered mineral is simply mixed with meal; and being soluble in even very dilute hydrochloric acid (and therefore in the gastric juice) it passes from a tasteless form into the poisonous barium chloride. In certain mining districts in the north of England poultry are not allowed to run on the waste heaps from the mines where perchance they might peck up a grain of witherite.

Strontianite. In the habit and grouping of its crystals this mineral resembles aragonite rather than witherite. These are columnar or spear-like and aggregated in bundles, and only occasionally show terminal faces (plate 75, fig. 6). Isolated, well-formed crystals are of the greatest rarity. Usually, the mineral forms divergent columnar of fibrous masses of a white, yellowish, or pale greenish colour. Such material is readily distinguished from aragonite by the flame test. The mineral dissolves with effervescence in dilute hydrochloric acid, and the solution imparts a rich carmine colour to the Bunsen-flame. The pure mineral contains: strontia (or strontium oxide, SrO) 70·2, and carbon dioxide (CO_2) 29·8 per cent.; frequently, however, a little calcium is present isomorphously replacing strontium. The specific gravity is 3·6 — 3·8, and the hardness $3^1/_2$.

The most abundant and important occurrence of strontianite is that in veins in the chalk formation at Hamm and Drensteinfurt (plate 75, fig. 6) in Westphalia. Other occurrences are in mineral-veins at Strontian in Argyllshire (from which locality this mineral and also the element strontium take their names), Clausthal in the Harz, Bräunsdorf near Freiberg in Saxony, and Leogang in Salzburg; none of these are, however, of any technical importance.

Strontianite is the most suitable raw product for the preparation of strontium compounds, and since it occurs in Westphalia in considerable quantities it is there won by mining. The compound most largely prepared is the oxide; but this cannot be obtained, like lime from calcite, by simply heating the mineral. It must be heated in the presence of steam or of coal, or better still with both of these. Strontium oxide is also prepared by igniting the nitrate. Strontium hydroxide, obtained by adding water to the oxide, is employed in the sugar industry, for the purpose of extracting from the molasses the whole of the sugar. The sugar combines with the strontium hydroxide to form strontium saccharate, which being difficultly soluble separates out. This is then treated with carbon dioxide, when the strontium is deposited as carbonate: the solution of sugar then remains to be evaporated and treated in the refinery. The product, although entirely freed from strontium, is known as strontium-sugar. Another use for strontium salts (here the nitrate) is for the production of the red light of fireworks. The demand for strontium is not met by the output from the Westphalian strontianite deposits; and in addition about 9000 tons of celestite are annually consumed.

Minerals of the Barytes Group.

In the aragonite group, which we have just considered, the three metals strontium, barium, and lead are in combination as carbonates; here we find them as sulphates, and forming another rhombic series of isomorphous minerals, namely celestite, barytes, and anglesite. The corresponding calcium salt although also rhombic exhibits wide differences in its form and cleavage, and it does not belong to this isomorphous group.

The three minerals of this group possess two sets of cleavage. The better developed of these is parallel to one of the three planes of symmetry, that is, parallel to one of the three pairs of parallel faces or pinacoids. The other cleavage is prismatic in two directions, which are perpendicular to the single pinacoidal cleavage. By some authors (Naumann and Zirkel, and Tschermak) the direction of single cleavage is chosen as the brachy-pinacoid in setting up the rhombic crystal: here (following Dana and Bauer) we make it the basal pinacoid, the face *a* in text-figs. 264—266. Neither of these methods is, however, well suited for pictorial representation, since there is considerable foreshortening and distortion of the tabular or prismatic form of the crystals. In the coloured plates 76—78 many of the crystals are therefore set up in still another position to show them to the best advantage: here the large basal plane is placed to the front, and the macro-axis (along which the crystals are often prismatically developed) is set vertically. For the correct orientation of the crystals the prismatic cleavages afford a useful guide: these are often to be seen as cracks perpendicular to the basal plane (e.g. plate 76, figs. 1, 2, and 4; plate 78, fig. 5). The basal plane is then placed horizontally, and the line bisecting the acute angle between the prismatic cleavages is set from right to left, that is, in the conventional direction of the macro-axis.

The close relation of these three minerals is at once apparent from their similarity in crystalline form, as shown in plates 76—78. The angles between corresponding faces are also nearly the same; for example, that between the prismatic cleavages is 101° 40′ in barytes, 104° in celestite, and 103° 45′ in anglesite. The last of these minerals has already been described with the lead ores (p. 122, and plate 17).

Barytes, or heavy-spar, is the most abundant of barium minerals. It takes its name, from the Greek βάρυς (heavy), on account of its high specific gravity of 4·5. Few minerals without metallic lustre and containing no heavy metal are so heavy as barytes, and of these barytes is by far the most widely distributed.

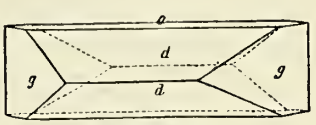

Fig. 264.
Crystal of Barytes.

The two isolated crystals represented in plate 76, figs. 2 and 4, are of the same form as that in text-fig. 264: their apparent difference in appearance being due to the different orientation. The two faces sloping away from the top of the crystals like the roof of a house (figs. 2 and 4) belong to the unit vertical prism parallel to the prismatic cleavages, and correspond to the faces $g = \infty P$ in the text-figure; the large face to the front is the basal plane ($a = 0\ P$); and the long narrow faces at the sides belong to a macro-dome ($d = {}^1/_2\ P\ \bar{\infty}$). In these two crystals we see also a beautiful zonal structure, marking out the periods of growth of the crystal: a brown kernel is surrounded by a colourless shell, and the two portions present a difference in their crystalline form. In the kernel the acute angle of the prism is truncated by a face of the brachy-pinacoid. At a later stage, when the crystal continued its growth in a purer solution free from iron oxide, this brachy-pinacoid became covered over, and the prism faces grew up to a sharp edge. Beautiful examples

of such zonal structures are common in the barytes crystals from the Mowbray iron mine at Frizington in Cumberland.

In fig. 1 we have again the same forms, together with a brachy-dome, shown as a broad face at the top. Here the prism faces (one is visible at the top left-hand corner) are quite small: and in crystals of the same form in fig. 5 they are absent. The latter picture is explained by text-fig. 265, in which the faces are the basal plane ($a = 0\,P$), a macro-dome ($d = {}^1/_2\,P\,\breve{\infty}$), and a brachy-dome ($f = P\,\check{\infty}$). Exactly the same faces are shown in text-fig. 266, but here the prismatic development is in the direction of the brachy-axis instead of the macro-axis, and the basal plane is smaller. Crystals of this habit are shown in plate 76, figs. 3, 6, and 12.

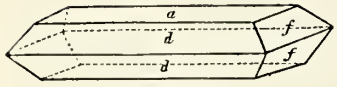

Fig. 265.

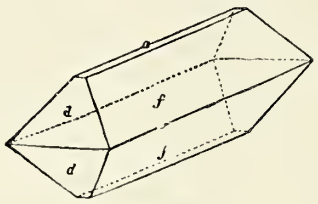

Fig. 266.

Crystals of Barytes.

The large rhomb-shaped plates in fig. 10 are bounded by the large basal plane with narrow prism faces at the edges. The tabular crystal in fig. 7 shows, in addition to these two forms, the brachy-pinacoid as narrow faces at the sides.

We thus see that barytes crystals may vary considerably in their habit, while at the same time there is little variation in the forms actually present. Faces of rhombic pyramids, though sometimes present, are never of large size. The common faces are sufficiently large and smoothly developed for the angles between them to be easily determined with the contact goniometer; we find:

$$\infty P \text{ to } \infty P\ (g \text{ to } g) = 101^3/_4{}^\circ;\ 0\,P : {}^1/_2\,P\,\breve{\infty}\ (a\,d) = 141^\circ;\ 0\,P : P\,\check{\infty}\ (a\,f) = 127^1/_4{}^\circ.$$

The crystals are at times grouped in an irregular manner on the matrix (plate 76, fig. 3); at other times they are grouped in a more regular fashion, giving rise to large parallel groups (plate 76, fig. 5; and plate 77). Or again, crystals of tabular habit may be aggregated in not quite parallel positions, giving rise to cockscomb (plate 76, fig. 11) and rose-like (text-fig. 267) forms. The latter, known as "barytes-roses" and very similar to the well-know "iron-roses" (p. 152), are found in sands of the Tertiary formation at Rockenberg, near Butzbach in Hesse. The figure shows a group of three rosettes, but single ones as well as much larger clusters are found. These crystals enclose a large amount of sand (up to 20 per cent.) in the same manner as the crystals of calcite from Fontainebleau (plate 72, fig. 8), and those of gypsum from Sperenberg (plate 79, fig. 4). Globular masses of barytes with an internal radial-fibrous or platy structure also occur; and sometimes dendritic forms like that of wollastonite shown in plate 2, fig. 5. Most frequently, the mineral forms coarsely grained and sparry

Fig. 267.

Rose-like aggregates of Barytes crystals ("Barytes-roses") from Rockenberg, Hesse.

masses showing a lamellar structure and a white or flesh-red colour: from such masses cleavage fragments having the form of rhomb-shaped plates may be readily detached. At times the material is finer grained and more compact.

Distinctly formed twinned crystals of barytes are unknown, but twinning is sometimes represented by the presence of fine twin-lamellae.

The range of colouring shown by barytes is well illustrated in plate 76. The crystals are occasionally colourless and transparent (fig. 1); but usually they are cloudy and of a pale yellow, brown, or reddish colour. Greenish and bluish crystals are less frequent. Attention has already been drawn to the colouring of the zonal crystals in figs. 2 and 4; here the brown colour is due to the enclosure of iron oxide. The crystal in fig. 9 owes its red colour to the presence of enclosed cinnabar. Other crystals enclose stibnite, orpiment, or realgar, which respectively produce a grey, yellow, or red coloration.

In the absence of crystalline form barytes may always be easily distinguished from other minerals by means of its high specific gravity of 4·5, its hardness of $3^1/_2$, and its behaviour when heated. A fragment held in the Bunsen-flame decrepitates violently, and at the same moment a pale green flash characteristic of barium is seen in the flame. When powdered and heated on charcoal with sodium carbonate, barytes gives the hepatic reaction (p. 63), proving the presence of sulphur. Pure barytes contains: baryta (BaO) 65·7, and sulphur trioxide (SO_3) 34·3 per cent. Sometimes the mineral contains a little strontium or calcium replacing the barium.

A variety of barytes known as Bologna-stone, or Bolognian spar, is found as nodular masses in clay at Monte Paterno near Bologna. This is of interest in being the material in which the phenomenon of phosphorescence was first studied in the year 1602 by V. Casciorolus, a shoemaker of Bologna. By heating the mineral with charcoal, barium sulphide is formed, and this, after exposure to the sun's rays, is seen in a dark room to emit light. The material so prepared was made into sticks and under the name of "Bolognian phosphorus" was a source of wonder in the olden days. This property is, however, also possessed by strontium sulphide and by calcium sulphide, and the intensity and colour of the light which is emitted varies with the composition of the material and on the presence of various impurities.

Barytes is one of the most difficultly soluble of minerals; and for this reason a soluble barium salt affords the best reagent for the detection of sulphuric acid, in the presence of which a heavy white precipitate of barium sulphate is immediately thrown down. A litre of pure water at 15° C. takes up only 3 milligrams of barium sulphate; but at a higher temperature and with the presence of other salts in the solution the solubility is appreciably greater. When solutions of barium chloride and sulphuric acid are mixed in the ordinary way, the barium sulphate is deposited as a fine, amorphous precipitate. But if the experiment be so arranged that the extremely dilute solutions shall mix very gradually, the barium sulphate is then deposited as minute crystals; and these more nearly resemble crystals of barytes when the solutions are the more dilute and the experiment the more prolonged. The crystals of barytes in nature must also have been deposited from solution, as is proved by their mode of occurrence. Here there may have been a mixing of two solutions; on the one hand a soluble barium salt (the chloride or the bicarbonate), and on the other a soluble sulphate (gypsum or iron-vitriol). Or the barium sulphate may itself have been held in solution and deposited with a fall in temperature or some other change in the conditions.

Owing to its low degree of solubility, barytes is little affected by weathering agents. Under certain conditions, however, when carbonated waters act on large masses it may be transformed into witherite. More often, quartz is the replacing mineral; in the Oden-

wald and Taunus, veins of barytes are sometimes replaced by quartz, and at Griedel, near Butzbach in Hesse, large pseudomorphs of quartz after barytes are found.

Barytes occurs in mineral-veins and other deposits in association with ores of lead, silver, cobalt, manganese, and iron; and under these conditions good crystallized specimens are found at many localities. For example, at Przibram in Bohemia (plate 76, fig. 3); Felsöbanya, Schemnitz, and Kapnik in Hungary; Ilfeld (plate 76, fig. 5; and with manganite in plate 34, fig. 5) and Clausthal in the Harz; Dufton in Westmorland. The best crystals are those found in considerable abundance in the iron (haematite) mines in the neighbourhood of Frizington in Cumberland (plate 76, figs. 2, 4, 10, 12).

Veins filled only with barytes, without metallic ores, though often with fluor-spar and quartz, are found in many districts. For example, in the Odenwald (plate 77), Meggen in Westphalia, and New Brancepeth Colliery near Durham. At these and other places the mineral is won by mining.

Barytes is the most abundant raw material for the manufacture of various barium preparations. Barium chloride is made by igniting an intimate mixture of powdered barytes, coal, and calcium chloride, this process being now carried out in the old Leblanc soda works. This salt, being readily soluble in water, finds many applications. When decomposed with Chile saltpetre it gives barium nitrate, which is used for producing the green light of fireworks. When ignited, barium nitrate gives barium peroxide (BaO_2); this when treated with dilute acid yields hydrogen peroxide (H_2O_2), which is extensively used for bleaching. In France alone about 1000 tons of barium peroxide are manufactured per annum. Barium sulphate precipitated from a solution of barium chloride is used under the name of "blanc fixe" for making white paint and for producing the surface of smooth printing papers. The white paint known in the trade as Griffith's white or lithophone is obtained by mixing solutions of zinc sulphate and barium sulphide. Large quantities of the coarser white paints are made by simply mixing finely powdered barytes with oil.

Celestite. The similarity between crystals of celestite and of barytes is remarkably close; and, indeed, it is not always possible to distinguish between the two until the angles between the faces are measured or a chemical test is made. The fine crystals from the sulphur mines in Sicily (plate 76, figs. 1—3) were at one time, before they had been critically examined, regarded as barytes; and the crystals in fig. 7 might easily be mistaken for barytes by even an experienced mineralogist. The crystals from certain well-known occurrences present certain small distinctive features, and having once seen them, we recognize these crystals again as celestite without troubling to test them every time.

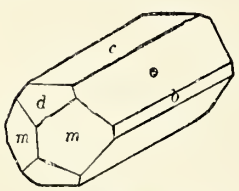

Fig. 268.
Crystal of Celestite.*)

This striking similarity between the shapes of the crystals of the two substances is at once apparent from a comparison of plates 76 and 78. The large celestite crystal in fig. 5 shows the same combination of forms, and these are developed to approximately the same extent as in the barytes crystal in fig. 1. In the same way celestite fig. 7 compares very closely with barytes fig. 4; and text-fig. 264 serves as an illustration of either one or the other. The celestite figs. 1—4 resemble the barytes crystals in figs. 3 and 6, differing slightly in the presence of small faces of the prism. These are illustrated by text-fig. 268; c is the basal plane $0\,P$ (which in the pictures is rather narrower than shown in the text-figure), o a brachy-dome $P\breve{\infty}$, d a macro-dome $^1/_2\,P\bar{\infty}$, m the unit

*) The faces lettered $c\,o\,d\,m$ on this crystal correspond respectively to those lettered $a\,f\,d\,g$ in the crystals of barytes in text-figs. 264—266.

vertical prism ∞P, and b the brachy-pinacoid $\infty P \breve{\infty}$. Here we have a pronounced prismatic habit of the crystals in the direction of the brachy-axis, and such crystals are usually attached to the matrix at one end of this long brachy-dome (fig. 2).

In fig. 6, however, is shown a crystal of celestite which finds no counterpart amongst barytes: here we have a combination of a rhombic pyramid with a small basal plane.

Crystals of celestite are sufficiently large and their faces smooth enough for the angles to be determined with some degree of accuracy with the contact goniometer. The angle of the cleavage prism, ∞P to ∞P, is 104° 10′, and that between the faces of the brachydome o has very nearly the same value, namely 104° 0′. The angle $0P : P\breve{\infty}\ (c\ o) = 128°\ 0'$, and $0P : {}^1/_2 P\bar{\infty}\ (c\ d) = 140°\ 35'$.

Pure celestite is quite colourless, but in many crystals there is a bluish shade of colour as represented in plate 78. The crystals in fig. 1 are faintly tinted with blue only at their ends, whilst in figs. 5—7, 9, and 10 the colouring is fairly uniform. Usually the blue colour is quite pale, but in figs. 6 and 9 it is more intense. The mineral was first recognized at the end of the eighteenth century in specimens from Frankstown in Pennsylvania, where it occurs in limestone as platy masses with a fibrous structure and a deep sky-blue colour (similar to the specimen in fig. 9); and it was on account of this sky-blue colour that the mineral received the name celestite.

When heated before the blowpipe, celestite decrepitates and colours the flame a deep carmine, thus indicating the presence of strontium. The pure mineral contains: strontia (SrO) 56·4, and sulphur trioxide (SO_3) 43·6 per cent.; a portion of the strontium may be replaced by small amounts of calcium or barium. The specific gravity, though high, 4·0, is appreciably lower than that of barytes: the hardness is $3^1/_2$.

Beautifully crystallized specimens of celestite are found in some abundance in the sulphur mines in the neighbourhood of Girgenti in Sicily (plate 78, figs. 1—3). Fine crystals lining cavities in the massive material are found in the red marls of Triassic age in Gloucestershire and Somersetshire, particularly in the neighbourhood of Bristol (fig. 4). Here the mineral is mined to the extent of about 20,000 tons per annum. Large crystals, sometimes reaching a foot across and of a delicate blue colour, are found on Strontian Island in Put-in-Bay on the Ohio side of Lake Erie (fig. 5).

Large yellow crystals, beautifully and sharply formed, are found in nummulitic limestone on Jebel Mokattem near Cairo in Egypt (fig. 8). The crystals of pyramidal habit (fig. 6) occur in limestone at Brady's in Mineral Co., West Virginia. In Germany, good crystals are found together with large masses of sparry celestite in Zechstein marl at Gemböck near Corbach in Waldeck (fig. 7), and at Giershagen near Stadtberge in Westphalia. Blue fibrous celestite has long been known from the Muschelkalk at Dornburg near Jena (fig. 9); and material very similar to this occurs in Jurassic clay on the Eichberg near Blumberg in Baden, and also at Frankstown in Pennsylvania. The fibrous structure is now regarded as pseudomorphous after gypsum. Celestite occurs also in mineral-veins, as at Scharfenberg in Saxony, Herrengrund in Hungary, and Leogang in Salzburg.

Being the most abundant of strontium-bearing minerals, celestite is of importance for the manufacture of salts of strontium. It is converted into the readily soluble carbonate by digestion under pressure in a solution of soda; or it is first roasted with coal with the formation of strontium sulphide, which by the action of carbon dioxide is converted into carbonate. The product is applied for the same purposes as strontianite (p. 394).

Gypsum and Anhydrite.

These two minerals are related to one another, but in a different manner to those considered in the last few pages. In their crystalline form they possess no feature in common; but they show resemblances in their chemical composition and their mode of occurrence and origin. Both consist of calcium sulphate, but in gypsum this is combined with two molecules of water, whilst in anhydrite there is no water, as indicated by the name. Such a name might, however, have been equally well applied to many other anhydrous minerals; and its use is more for the purpose of emphasizing the difference between these two forms of calcium sulphate. As to their similarity in mode of occurrence, it may be mentioned that they are frequently found together in salt-deposits, having been formed, like the rock-salt, as a deposit from sea-water. Gypsum has, however, several other modes of occurrence, and for this reason it was not described with the minerals more closely allied to rock-salt.

Gypsum. Being a mineral of wide distribution and frequent occurrence, and with characters that attract the eye, gypsum has been known since very early times, in spite of the fact that it contains no useful heavy metal and that it is much too soft for use as a gem-stone. It is sometimes found as clear, colourless and transparent masses, which are so soft that they can be readily scratched even by the finger-nail. Owing to the possession of a highly perfect cleavage in one plane direction such masses can be readily split into thin plates. Cleavage plates of gypsum have at times been used for windows; and the ancient Romans placed such windows in their bee-hives so that the bees could be seen at work. Small cleavage flakes of gypsum produce a spangled effect and have long been used for decorating statues of the Virgin. On this account gypsum (in common with mica, p. 332) has received the popular name *Maria-glass* (*glacies Mariae*), and, in German, Marienglas and Frauneis.

In addition to the very perfect cleavage mentioned above, gypsum possesses two other cleavages. The intersections of these on the first cleavage are inclined at an angle of $114\,^1/_2{}^0$; and the result of the three cleavages is the production of rhomb-shaped platy cleavage fragments, as shown in the left-hand portion of plate 80, fig. 2. Of the two latter cleavages, one is distinguished as the fibrous cleavage, and its presence is very often shown by the fine lines on the surface of the more perfect cleavage. The other is much less perfect, and owing to its somewhat irregular and rounded surfaces it is known as the conchoidal cleavage.

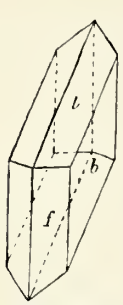

Fig. 269. Simple (untwinned) crystal of Gypsum.

Crystals of gypsum bounded by plane faces on all sides are of common occurrence, and it is easily seen that these (plate 79, fig. 2) possess only a single plane of symmetry: they therefore belong to the monoclinic system. The pair of faces of the clino-pinacoid $\infty P \infty$ (*b* in text-fig. 269) is rarely absent, and this is the direction of the highly perfect cleavage. In addition, we usually find two prismatic forms, each consisting of four faces. One of these is taken as the unit vertical prism ∞P (*f* in text-fig. 269), and the other as a negative hemi-pyramid $-P$ (*l*). The angle between adjoining faces of the vertical prism is $111\,^1/_2{}^0$, and that between faces of the hemi-pyramid is $143\,^3/_4{}^0$, as may be easily determined with the contact goniometer. The text-figure corresponds with the crystal in plate 79, fig. 2. Sometimes, in addition to the faces above noted, there is a positive hemi-pyramid $+P$, as in fig. 1, but being behind it is not visible in the picture.

Crystals of gypsum are, however, not always developed with perfectly plane faces and straight edges as in the two examples just referred to. Frequently they are rounded and curved, as shown in plate 79, fig. 3; and when the vertical prism and the pinacoid are absent such crystals may be quite lenticular in form (plate 80, fig. 4). In these and other puzzling cases, the crystals can, however, always be easily orientated by the help of the three cleavages. The perfect cleavage is parallel to the clino-pinacoid or plane of symmetry, which truncates the side or acute edges of the vertical prism; the conchoidal cleavage is parallel to the ortho-pinacoid $\infty P \bar{\infty}$, which truncates the front or obtuse edge of the vertical prism; and the fibrous cleavage is parallel to the pair of faces of the positive hemi-pyramid $+P$, which truncates the top of the crystal in plate 79, fig. 2.

Twinning is of frequent occurrence in crystals of gypsum, and several of the characteristic forms so produced are represented in plate 80. Most often the twin-plane is the ortho-pinacoid, the two individuals having the conchoidal cleavage in common. The cleavage fragment in plate 80, fig. 2, shows distinctly the junction of the two individuals along the vertical line (which is the trace of the twin-plane on the perfect cleavage), and the re-entrant angle (132°) formed by the fibrous cleavage of the two portions. The long crystal in fig. 1 of the same plate is also a twin of this kind: at first sight it has the appearance of a simple crystal, but the twinning is betrayed by the re-entrant angle (132°) shown by the fibrous cleavage (represented in the picture by fine lines one-third of the way from the top). In text-fig. 270 we have the same twin, only here the re-entrant angle is formed by the negative hemi-pyramid *l*. Twinned crystals of this kind are of frequent occurrence, and on account of their characteristic shape they are known as "swallow-tail twins". They usually occur attached to the matrix with the re-entrant angle at the free end; and are so found in the drusy cavities of the rock-salt deposits.

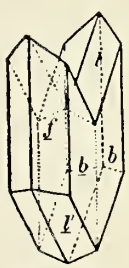

Fig. 270.
Twinned crystal of Gypsum.

Twins of another kind are met with in the crystals with rounded faces which occur embedded in clay, sand, or massive gypsum (plate 80, figs. 4 and 5, and as a cleavage plate in fig. 3). Here the twin-plane is a face of the negative ortho-dome $-P\bar{\infty}$, which truncates the edge of the the hemi-pyramid *l*. The re-entrant angle (at the top of fig. 3) is formed by the faces of the vertical prism *f*; and the fibrous cleavage of one individual falls almost in a line with the conchoidal cleavage of the other individual.

The crystals are sometimes bent in curious zig-zag and twisted forms, just as if they had been sticks of wax subjected to pressure. The best examples of such bent crystals are found in a gypsum cave at Reinhardsbrunn in the Thuringian Forest (plate 80, figs. 6 and 7).

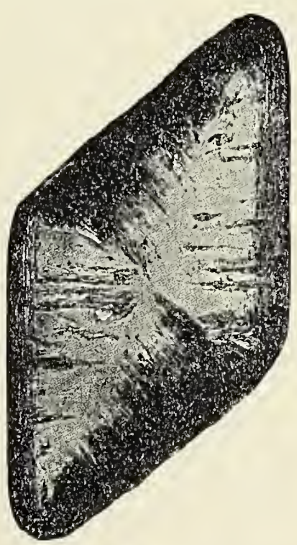

Fig. 271.
Crystal of Gypsum with "pyramids of growth."

In colour the crystals range from colourless to grey or pale yellowish. Sometimes they enclose considerable quantities of clay or sand (plate 79, fig. 4); and occasionally these enclosures are arranged within the crystal in a regular manner. In text-fig. 271 the areas extending from one set of faces are clouded by enclosed material, whilst the alternate areas are clear. Clear crystallized gypsum is often distinguished by the name *selenite*.

When occurring in large masses, the mineral presents a fine-grained texture with a snow-white, grey, yellow, or red colour; and often these colours are distributed in bands,

veins, and patches. Material more compact in texture is the well-known *alabaster*, which on account of its softness is easily carved; it takes a good polish and much resembles marble in appearance, but is less serviceable than this. A particular variety of this shows serpentine or contorted banding (plate 79, fig. 7) and is known as "snake-alabaster" or "tripe-stone". Here a grey gypsum loaded with clay is traversed by crumpled veins of pure white gypsum. The material consisted originally of anhydrite, and the crumpling of the veins has been brought about by the increase in volume which accompanied the transformation of anhydrite to gypsum (p. 405). Veins of gypsum frequently exhibit a fibrous structure, the fibres being arranged perpendicularly to the walls of the vein. This fibrous gypsum (plate 79, fig. 6) displays a silky lustre, which is the more pronounced the finer the fibrous structure; this variety is known as *satin-spar*.

Of the physical characters of gypsum, mention has already been made of the low degree of hardness (No. 2 on the scale). The specific gravity is also low, being only 2·3. Being a bad conductor of heat, the mineral does not feel cold to the touch: and this character, together with the difference in hardness, affords a ready means of distinguishing between alabaster and marble. The refractive power is low, the mean index being 1·5228, and the double refraction is moderately strong. Thin cleavage fragments of gypsum display brilliant and clear interference-colours in parallel polarized light; and being readily obtained they afford the best material for the study of this phenomenon. Thin plates of gypsum are cut and skilfully put together to give various patterns or to represent flowers, butterflies, etc., and are supplied by the microscope dealers. These objects show in a very beautiful manner the production of brilliant polarization-colours with the aid of a colourless crystallized material.

Another optical phenomenon well illustrated by gypsum is that of the change in form of the biaxial interference-figure (plate 4, fig. 4) with change in temperature. To show this a plate, cut from a crystal in the correct direction, is warmed on a water-bath (in a covered porcelain dish over boiling water), quickly transferred to the stage of the polariscope, and viewed in convergent polarized light. The dark hyperbolic brushes are at first seen to be in contact and the rings are circular, the figure being then a uniaxial one (as in plate 4, fig. 1); but the brushes quickly separate, moving outwards towards the edge of the field of view. With a more suitable arrangement, by means of which the crystal section can be heated in a current of hot water on the stage of the microscope, the brushes are seen to approach until they meet in the centre, the figure becoming uniaxial at a temperature of 91° for sodium-light; and then with still rising temperature to open out again in a direction at right angles to that which they at first occupied. Here we have not only a change in the value of the angle between the optic axes, but also a change of the optic axial plane itself.

Corresponding with the chemical formula $CaSO_4 . 2\,H_2O$, gypsum contains 20·9 per cent. of water. When heated to 107—130° C. three-fourths of this water is expelled, and the mineral becomes cloudy and white, finally falling to powder; the product is known as calcined or burnt gypsum, or as the half-hydrate. This powder — the well-known plaster of Paris — possesses the property of reabsorbing the amount of water it has lost, with the formation again of gypsum: when mixed with water it soon sets to a hard mass. On this property depends the extensive use of plaster of Paris for making casts and in stucco work. When gypsum is heated to 400° C. the last traces of its water are expelled, and the material (dead burnt gypsum) can then no longer be used for making casts. An intermediate stage is, however, possible; for in hydraulic gypsum or Keene's cement the material, although completely dehydrated, is still capable of combining again with water, hardening after a few days and very gradually returning to the normal composition of gypsum. The re-

searches of van't Hoff have proved that gypsum when heated alone is completely dehydrated at a temperature of 190° C. and the material still possesses the property of re-combining with water; but that this property is lost if the heating be long continued or if the temperature is higher. This is, however, not quite in agreement with the statements in works on technological chemistry, it being said that hydraulic gypsum is manufactured by burning the mineral at a red-heat. This product sets as a hard compact mass very resistant to the weather and therefore very suitable for use as a mortar.

Gypsum is comparatively easily soluble in water, namely, one part in 400. The solubility is appreciably increased in the presence of sodium chloride; a salt solution taking up one part of gypsum in 120 parts of solution. Since gypsum is frequently associated with rock-salt, the extensive solution which beds of gypsum have often suffered is not surprising. Irregular channels and pipes, and even large caverns, are dissolved out in the solid gypsum: and, as the roofs of these fall in, local miniature earthquakes result and funnel-shaped depressions are formed in the surface of the ground. These depressions may become filled with water, forming small lakes. The same things also at times happen in rock-salt and limestone districts.

At the earth's surface gypsum is the most stable form of calcium sulphate, and consequently the most abundant. The bedded deposits of gypsum occurring in association with rock-salt have been, as we have seen (p. 352), deposited directly from sea-water or have resulted by the alteration of beds of anhydrite. The crystals lining cavities in the solid gypsum and in the rocks of the salt formation owe their origin to the re-solution and re-deposition of the calcium sulphate. Owing to the easy solubility of gypsum in water and saline solutions the sides of the underground reservoirs in the salt mines (p. 353) soon become coated with quite large crystals; the pipes for conveying the brine become choked with gypsum crystals; and even the mine timbers become encrusted with beautiful swallow-tail twins.

There are, however, other ways by which gypsum may be formed in nature. Sulphuric acid, produced by the weathering of iron-pyrites and other sulphide minerals, may combine with the calcium of limestones or that present as small amounts in clays and various rocks. In this manner isolated crystals or groups of crystals may grow in beds of clay, sand, or lignite. Again, the sulphur dioxide gas and water vapour emitted by volcanoes and solfataras combine in the air to form sulphuric acid: this decomposes the volcanic rocks and combining with their calcium produces gypsum.

Localities for crystallized gypsum are extremely numerous: those mentioned above under rock-salt may be referred to, and here we need mention only a few of the more important. Fine crystals occur in the salt formation at Reinhardsbrunn in the Thuringian Forest (plate 80, figs. 1, 6, and 7): an enormous group of large, colourless crystals from this locality was presented to the British Museum by the Prince Consort in 1847. Beautiful groups of clear, sharply-developed crystals come from the salt mines at Bex in Canton Wallis, Switzerland (plate 80, fig. 2). In clays of Tertiary age crystals are found at Halle in Prussia (plate 79, fig. 2), Hochheim and Flörsheim on the Main in Hesse-Nassau (plate 79, figs. 3 and 5), and in the railway tunnel near Mainz (plate 80, fig. 5). Groups of crystals are found in sand at Sperenberg near Berlin (plate 79, fig. 4), and at Smyrna in Asia Minor. From other rocks of Tertiary age come the large swallow-tail twins of Montmartre near Paris (plate 80, fig. 3). Fine crystals are found in the sulphur mines in the neighbourhood of Girgenti in Sicily. In England, well-shaped crystals are found embedded in clay at many places. Gigantic crystals measuring a yard in length have been obtained in large numbers from a cave at South Wash in Wayne Co., Utah; and recently crystals of the same length have been found in a copper mine near Cloncurry in Queensland.

Extensive beds of massive gypsum occur in Germany on the southern borders of the Harz Mountains and the Kyffhäuser-Berg, near Gotha and other places in the Thuringian Forest, on the Lower Neckar and on the Kocher. Similar deposits are extensively mined in Nottinghamshire, Sussex, Cumberland, and other counties in England; also in the neighbourhood of Paris, in Nova Scotia, and many other parts of the world.

The "tripe-stone" represented in plate 79, fig. 7, is from the Zechstein formation at Eisleben on the borders of the Harz Mountains; and similar material has been found at Wieliczka and Bochnia in Galicia, Austria. In plate 70, fig. 12, massive gypsum is shown as the matrix of boracite crystals from Lüneburg in Hanover, where it is the only rock outcropping at the surface. Massive gypsum also forms the matrix of embedded crystals of aragonite in northern Spain and southern France (plate 74, figs. 6 and 7); of crystals of ferruginous quartz (plate 52, figs. 8 and 9); of dolomite at Hall in Tyrol; whilst in Sicily the gypsum beds contain rich deposits of native sulphur (p. 142).

Owing to its wide distribution, gypsum is one of the minerals that supply sulphur for the building up of legumin and albumen. The presence of dissolved gypsum gives rise to a permanent hardness in water; when such water is evaporated the gypsum is deposited as a crust inside kettles and boilers, and this is more difficult to remove than a crust of calcium carbonate.

Applications of gypsum. — Alabaster is employed as an ornamental stone for inside sculptural decorations and for carving into a variety of small ornaments. The fibrous satin-spar is sometimes cut into beads, which, like those of other minerals with a finely fibrous structure (cat's-eye and tiger-eye) display a moving band of light on their surface. Gypsum in its natural state or when burnt is employed in agriculture as a manure for clover, linseed, and other leguminous crops. Here it has probably also an indirect action in the soil by liberating potash from its combination with silicates. Calcined gypsum, or plaster of Paris, finds extensive applications, for moulds, casts, stucco and plaster work of many kinds. Hydraulic gypsum is said to have been used by the ancient Egyptians as mortar in building the Cheops pyramid. It was also used in Germany in the old castles and cloisters; and, after falling into disuse, it is now again employed for technical purposes.

Anhydrite. Whilst gypsum occurs beautifully crystallized in a variety of forms, anhydrite, on the other hand, presents no very attractive appearance. Its crystals are rare and always small with but few rough and striated faces. They belong to the rhombic system with usually a short-prismatic development (plate 78, fig. 11). The character most apparent to the eye is that given by the three perfect cleavages. These are parallel to the three planes of symmetry, that is, to the three pinacoids, and they are therefore at right angles to one another. The crystals can be broken up into cuboidal cleavage fragments; but these differ from true cubes in possessing different physical characters on their different faces. The cleavages are not quite of equal quality; one is more perfect, giving smoother and brighter surfaces of fracture, than the two others. Thin cleavage flakes are always traversed by fine cracks at right angles to one another, due to the two cleavages that are perpendicular to the plate. These afford good material for adjusting the positions of the analyser and polarizer of the microscope, for in parallel light they give straight extinction parallel to these cleavage cracks. The specific gravity of anhydrite is 2·9—3·0, and the hardness 3—3½.

Usually the mineral occurs as finely granular masses; but occasionally the texture is coarser and in such sparry masses the cleavage is a prominent feature. It is colourless, grey, red, or of a delicate blue shade; and, except when colourless, it is only slightly translucent. The blue colour is not permanent, fading on exposure to the light, or when the anhydrite is transformed into gypsum.

Anhydrite occurs in association with rock-salt, having been deposited together with this from concentrated sea-water. Indeed the presence of other salts is essential for the formation of anhydrite, since from a pure aqueous solution calcium sulphate separates as gypsum. The chlorides of potassium and magnesium also present in the concentrated sea-water exert a sort of attraction for the water, and constrain the calcium sulphate to crystallize as anhydrite (p. 353). In contact with water anhydrite is unstable, and it becomes altered into gypsum. This change is accompanied by an increase in volume of about 60 per cent., 1000 cubic metres of anhydrite giving rise to 1600 cubic metres of gypsum. This is, however, only true if no calcium sulphate is removed in solution by the waters effecting the change. Owing to this solution the actual increase in volume may be much less than above stated, but still sufficiently great to be in evidence, as indicated by the following examples: the crumpling of thin bands of anhydrite in tripe-stone (p. 402; plate 79, fig. 7); the closing up of fissures in the anhydrite cover of the rock-salt beds (p. 352); galleries driven through beds of anhydrite become gradually closed up, and must from time to time be enlarged; strata at the surface lying immediately over anhydrite beds become bulged upwards and cracked. Near the surface, beds of anhydrite soon become transformed into gypsum; beds lying deeper are preserved as pure anhydrite; whilst at an intermediate depth the beds consist of a mixture of the two minerals.

Small crystals of anhydrite bounded on all sides by faces are found embedded in kieserite at Stassfurt and Leopoldshall in Prussia (plate 78, fig. 11). Granular anhydrite showing a crystallized surface is known from Aussee in Styria and Berchtesgaden in Bavaria. Coarsely granular anhydrite of a red colour is found at Berchtesgaden and in the Salzkammergut. Blue, fine-grained material is from Sulz on the upper Neckar in Württemberg, and from Vulpino in Lombardy.

Anhydrite has also been observed, although rarely, in mineral-veins, as at Andreasberg and Kapnik; and in the lava flows of volcanoes, as at Vesuvius and Santorin.

One of the few applications of anhydrite is as a manure; but being less soluble than gypsum, or even than" dead burnt gypsum", it is of much less value than this. The blue, compact anhydrite of Vulpino, known as "vulpinite", is cut and polished for ornamental purposes.

Apatite.

Phosphoric acid, a substance essential for the nourishment of plants and animals, has already been mentioned on various occasions in the preceding pages; namely, as a by-product in the smelting of iron (p. 160), and as a constituent of the precious stone turquoise (p. 260) and of the lead ore pyromorphite (p. 124). The minerals just named are phosphates, and there are very many others belonging to this group, but only few of them are of much importance. Of these apatite easily takes the first place, for it forms the source of phosphoric acid for all other phosphate minerals and it supplies the phosphates present in soils. The extremely wide distribution of this important mineral was first recognized with the aid of the microscope; it having been found that minute crystals of apatite are present in almost all kinds of igneous rocks. Such rocks are met with at many places throughout the world, and when they are broken down by weathering agents their materials are scattered broadcast over the whole surface.

Apatite crystallizes in the hexagonal system, as is evident by a glance at the well-formed crystals represented on plate 81. The model-like crystal in fig. 6 is, for example, bounded by a hexagonal prism, a hexagonal pyramid of the same order, and the basal

pinacoid. This pyramid is selected as the primary pyramid P, and its faces make with the base an angle of $139^{3}/_{4}{}^{0}$. The same combination of forms is also shown by the crystals in figs. 10 and 12; and those in figs. 7, 8, and 11 differ only in the absence of the basal pinacoid. The violet crystals in figs. 4 and 9 are bounded by only the prism and the base. The more complex crystals in figs. 1—3 are illustrated by the text-fig. 272. The hexagonal prism a and pyramid x, both of the first order, and the basal pinacoid c are the same as before. The small faces s lying directly over the prism edges are those of a pyramid of the second order. Between s and a, but only on one side (the left in the text-figure), there are other small faces u; these have the position of a twelve-sided double pyramid or a dihexagonal bipyramid, but with only the alternate faces developed. The six faces above together with the six parallel faces on the lower part of the crystal form a hexagonal bipyramid, which is described as a pyramid of the third order. Apatite thus belongs to the parallel-faced hemihedral or pyramidal-hemihedral class of the hexagonal system. The faces shown in the text-figure have the following Naumannian symbols: —

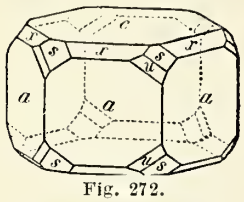

Fig. 272.
Crystal of Apatite.

$$a = \infty P,\ x = P,\ c = 0\ P,\ s = 2\ P\,2,\ u = \frac{3\ P\frac{3}{2}}{2}.$$

Comparing now these forms with the crystals on plate 81, in fig. 1 we have a large development of both the prism and the base, and on the edges between these are the narrow faces of two pyramids of the first order. The faces of the pyramids of the second and third order are very small: that of the third order, which just catches the light, is seen to lie on the right-hand side of the prism edge (i.e. on the opposite side to that shown in the text-figure). In fig. 2 the prism faces are short and the crystal consequently of a thick-tabular habit: here the faces of the pyramids of the second and third orders are rather larger, and that of the third order (again catching the light) is on the left of the prism edge. In this specimen several smaller crystals are attached to the main crystal in parallel position. In fig. 3 the comparatively large pyramid face of the second order reflects the full light, and there is no pyramid of the third order.

The crystals may vary in habit from tabular parallel to the base, to prismatic and columnar. The microscopic crystals seen embedded in igneous rocks are needle-like in form. Sometimes the edges of the larger crystals are curiously rounded presenting quite a fused appearance (figs. 5 and 7). Etched figures produced artificially by the action of acids on the basal plane show the same one-sided orientation as a pyramid of the third order; proving again the pyramidal-hemihedral symmetry of the crystals. Formerly apatite was confused with beryl and other minerals whose crystals present a columnar development; and on this account the mineral receives its name, from the Greek ἀπατάω, I deceive.

There is no distinct cleavage; but the crystals are frequently penetrated by fissures (plate 81) more or less irregular in direction but with a tendency to approximate to the basal plane. This indicates the presence of a poor cleavage parallel to the base, and is often to be seen more distinctly in rock-sections under the microscope. The outlines of these crystals as seen in section are either hexagonal, or elongated and more or less rectangular (plate 59, fig. 6). The former being perpendicular to the principal axis of the crystal remain dark in polarized light, whilst the latter show grey or white colours of the first order and extinguish parallel to their length. These microscopic crystals are colourless, but sometimes clouded by dusty enclosures in their centres. They were the first crystals to separate from the igneous magma, and were consequently caught up and enclosed in the later formed crystals. In plate 59, fig. 6, the small crystals are embedded in a large

crystal of augite which forms part of the rock mass. The refractive power of the crystals is moderately strong, the index for the ordinary ray being $\omega = 1{\cdot}646$ and for the extra-ordinary ray $\varepsilon = 1{\cdot}642$ (for sodium-light): on this account the crystals stand out in relief, and are thus readily distinguished from crystals of nephelite which have the same form.

The colour of apatite extends over a considerable range; and the crystals represented in plate 81 were partly selected with the view of illustrating this. The crystals may be colourless, yellowish-green, bluish-green, greenish-blue, violet, rose-red, mouse-grey, etc. The nature of the colouring material is not known. The specific gravity is 3·2; and the hardness, No. 5 on the scale, is about the same as that of window-glass.

In chemical composition apatite is a calcium phosphate, but in addition to phosphoric acid and lime it also contains chlorine or fluorine or both of these elements. The exact manner in which these constituents are combined is not known, and the formula may be written in different ways; here we give it as representing a double salt $3\,Ca_3P_2O_8 . Ca(Cl, F)_2$. The mineral contains: phosphorus pentoxide (P_2O_5) 41—42, lime (CaO) 54—55½, fluorine (F) 0—3·8, chlorine (Cl) 0—6·8 per cent. Apatite is strictly isomorphous with pyromorphite (p. 124) and mimetite (p. 125), possessing an analogous chemical composition and very nearly identical crystalline form. For the purpose of identifying the mineral and distinguishing it from others of similar appearance it is often advisable to test for the presence of phosphoric acid: this is most conveniently done with a solution of ammonium molybdate in nitric acid, which after standing for a little time gives with phosphoric acid a characteristic canary-yellow precipitate.

Being a calcium salt, apatite is subject to alteration when exposed to weathering agents, giving place to the more stable calcium carbonate. It becomes dull, white, and softer, and often fissured. The crystal in plate 81, fig. 10, has been partly altered in this manner; here water has also been taken up and these crystals are known as "hydroapatite".

The occurrence of apatite as microscopic crystals in igneous rocks has already been mentioned. Larger, but still indistinctly-formed crystals occur embedded in crystalline schists. Bright crystals of a thick-tabular habit and rich in faces are found in drusy cavities in gneissose rocks (plate 81, figs. 1—3) and in veins of tin ore (figs. 4 and 9). The large crystals of prismatic habit (figs. 5—8) usually occur embedded in crystalline limestone.

A few of the more important localities for crystallized apatite are the following. The tin mines at Ehrenfriedersdorf in Saxony (plate 81, figs. 4 and 9). At Schwarzenstein (figs. 1 and 2) and Floitenthal (fig. 3) in the Zillerthal, Tyrol: beautiful, water-clear crystals of the same type occur with epidote at the Knappenwand in Untersulzbachthal, Salzburg. As large masses in connexion with gabbro at Bamle, Kragerö (fig. 11), Arendal, and Snarum (fig. 10) in southern Norway. Rich deposits, sometimes reaching ten feet in thickness, occur in crystalline limestone in Ontario and Quebec, Canada; here large crystals, often with rounded "fused" edges (figs. 6, 7, 8, and 12), are found in great abundance. Similar occurrences are also met with at Gouverneur in St. Lawrence Co., New York (fig. 5) and elsewhere in the United States.

In southern Norway and Canada crystallized apatite occurs in sufficient abundance to be won by mining and used for the manufacture of artificial manures.

Phosphorite and **Rock-phosphates.** Calcium phosphate also occurs in great variety as fine-grained, compact or earthy masses; and materials of this nature have been distinguished by a number of special names, according to differences in character or mode of origin. The true phosphorite forms concretionary and stalactitic masses with a mamillated surface and internally a minute radially-fibrous structure. It occurs as a filling in veins and pockets in limestone, particularly in Quercy, France, and in Estremadura, Spain. Material of this kind from Staffel in Hesse-Nassau has received the special name staffelite

(plate 81, fig. 13). In addition to calcium phosphate, such material contains calcium carbonate, iron, alumina, and fluorine. Its value depends on the presence of phosphoric acid, but this, being in an insoluble form, cannot be readily assimilated by plants. The raw material has to be chemically treated; and this is now extensively done by the process first suggested by Liebig. By the action of sulphuric acid the insoluble tricalcium phosphate is converted into the soluble monocalcium salt, the remainder of the calcium combining with the sulphuric acid and water with the formation of gypsum. This reaction is represented by the following equation:—

Tricalcium phosphate	Sulphuric acid	Water	Monocalcium phosphate	Gypsum

$$Ca_3(PO_4)_2 + 2\ H_2SO_4 + 4\ H_2O = CaH_4(PO_4)_2 + 2\ (CaSO_4 . 2\ H_2O).$$

The product, consisting of a mixture of monocalcium phosphate and gypsum, is known as *superphosphate*. Since large quantities of sulphuric acid are consumed by this process, the artificial manure works often include a plant for the manufacture of this acid, as is also the case in the Leblanc soda works (p. 357). The ordinary superphosphate contains 14—18 per cent. of phosphoric acid soluble in water, together with much gypsum. A richer product, known as double superphosphate, and containing 40—50 per cent. of soluble phosphoric acid, is manufactured by the action of a solution of phosphoric acid on a more readily decomposed phosphorite; the solution of phosphoric acid required in this process being itself prepared by the action of dilute sulphuric acid on phosphorite. The fluorine contained in the phosphorite is set free as hydrofluoric acid, which together with other objectionable fumes must be carried away through very high chimneys. The presence of iron has an injurious effect in these artificial manures, since it combines with the phosphoric acid forming an insoluble iron phosphate.

The deposits of the so-called Lahn phosphates occurring at Weilburg on the Lahn in Germany are now almost exhausted, that still remaining being of little value owing to the presence of much iron. The English deposits are also now exhausted: here the material — the so-called coprolites — consisted largely of the fossil excrements of saurians and other extinct animals. Extensive deposits of phosphorites and rock-phosphates of various kinds are now worked in Estremadura in Spain, on the Somme in France, in Algeria and Tunis, and more especially the rich deposits in Florida and South Carolina. The Florida phosphate, treated in large quantities at Biebrich on the Rhine and elsewhere, contains about 80 per cent. of calcium phosphate, together with 2—5 per cent. of fluorine, 1 per cent. of ferric oxide, and 1 per cent. of alumina.

A rock-phosphate of comparatively recent formation, and known as sombrerite, occurs on the island of Sombrero in the West Indies. This has been formed by the action on the coral-limestone of phosphatic solutions leached from the overlying deposits of guano.

Another source of phosphoric acid made use of for artificial manures is the Thomas slag (basic slag) from iron furnaces (p. 160). The Thomas meal prepared from this contains 12—23 per cent. of phosphoric acid; this is not present in a form soluble in water, but the larger part is dissolved by weak acids, such as citric acid.

Superphosphate is used principally for the manuring of grain crops; and Thomas meal, being slower in its action, for pastures and vineyards. By mixing superphosphate with ammonium and potassium salts and with saltpetre the various brands of artificial manures suited for different crops are prepared. Enormous quantities of phosphates are consumed for agricultural purposes. In Germany alone the annual consumption amounts to about 500,000 tons of superphosphate, 400,000 tons of slag phosphates, and 70,000 tons of bone-meal and guano, of the total value of about five million pounds (compare p. 373).

Monazite.

This mineral, first discovered in 1829, took its name from the Greek word μονάζειν 'to be solitary', because of the rarity of its singly-occurring crystals; and for many years afterwards it was regarded as a mineral of rare occurrence. When, however, with the development of incandescent gas lighting, a commercial demand was created for substances which occur as constituents of this mineral, it was found in considerable quantities; and new occurrences of the mineral are now eagerly sought for to meet the increasing demand for this purpose.

The mineral as found in large quantities and used commercially has the form of small grains, being known as monazite-sand. Distinctly shaped crystals are rare (plate 82, figs. 1 and 2); they belong to the monoclinic system. In text-fig. 273 the large face to the front is the ortho-pinacoid ($a = \infty P \bar{\infty}$); above and below this are two ortho-domes ($x = -P \bar{\infty}$, $w = P \bar{\infty}$); at the sides the vertical prism ($M = \infty P$); and above the prism there is a pyramid ($p = P$). All of these faces are distinctly shown by the crystal in fig. 2: that in fig. 1 is bounded at the end by a large obliquely-placed cleavage surface. Twinned crystals of monazite, with the ortho-pinacoid as twin-plane, sometimes occur.

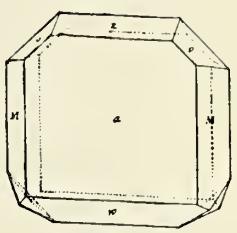

Fig. 273.
Crystal of Monazite.

The colour of the crystals is usually reddish-brown, and that of monazite-sand resinous yellow. The larger crystals are dull and opaque; but small crystals and grains are bright and translucent. The high specific gravity of 4·7 to 5·25 is an important character; for it enables the mineral to be readily separated from other lighter minerals by a process of washing in water, and in nature it has caused the accumulation of the heavy grains of monazite in certain deposits of sand.

Chemically, monazite is a phosphate of the rare metals of the cerium group, the formula being (Ce, La, Di) PO_4. But in addition to cerium, lanthanum, and didymium, it often contains some yttrium and thorium. The amount of thorium oxide (thoria, ThO_2) may range from 1 to 11 per cent. The variations in the amounts of these earths are illustrated in the following table of partial analyses of material from various localities.

	Raade, Norway.	Goyaz, Brazil.	Minas Geraes.	North Carolina.
Cerium earths $(Ce, La, Di)_2O_3$ . . .	56·86	64·1	51·0	40·86
Yttria (Y_2O_3)	2·76	5·1	2·2	13·98 (+ ZrO_2)
Thoria (ThO_2)	9·03	7·6	2·4	1·43

Monazite is of wide distribution as an accessory constituent of granite, diorite, gneiss, and other crystalline rocks. Usually, however, it is present in only very small amount; and its presence can only be detected by crushing the rock, separating the heavy minerals by washing in water, and examining the heavy residue so obtained under the microscope. With the weathering and breaking down of the rocks this concentration of the monazite is effected naturally; the grains collecting in the alluvial deposits of rivers, and in certain cases on the seashore. This mode of occurrence is exactly like that of gold and platinum in alluvial sands and of precious stones in gem-gravels; and it is such deposits that supply the commercial material.

Monazite-bearing sands formed in the manner just mentioned have been recorded from all parts of the world; but it is only in Brazil and North Carolina, and to a lesser extent in South Carolina, that they occur in sufficient abundance to be worked on a

commercial scale. In the Carolinas the alluvial deposits are worked in the valleys of several streams that rise in the South Mountains. The sands contain from traces up to 1 or 2 per cent. of monazite, and they are concentrated by the ordinary methods of the gold miner. The heavy residue contains the monazite mixed with a variety of other minerals, such as gold, zircon, rutile, garnet, corundum, magnetite, etc. The gold is separated by amalgamation with mercury, and magnetic minerals are separated with the help of the electro-magnet. The resulting product contains 65—75 per cent. of monazite. In Brazil the monazite-bearing sands are found at certain spots on the seashore near Alcobaca and Prado in the southern part of the State of Bahia, and also at various points along the coast of the States of Espirito Santo and Rio de Janeiro. Much of this sand has been shipped as ballast.

Larger crystals of monazite are found embedded in the felspar of the pegmatite veins in the Ilmen Mountains in the southern Urals, and at several places in the south of Norway. In the Norwegian felspar quarries the crystals are at times quite large (plate 82, fig. 1); they occur singly, and are collected to the extent of about one ton per annum. Tiny, brilliant crystals of monazite are found in the crevices of the gneissic rocks of the Alps and of the slates at Tintagel in Cornwall.

Monazite is by far the most important source of the thorium and cerium compounds used for the manufacture of the mantles for incandescent gas lighting. The fact that certain rare earths give out a brilliant light when strongly heated was discovered by Auer von Welsbach in 1880. Of these the most important is thoria; but pure thoria itself is not effective, and it requires to be mixed with some cerium earths to produce the best result. The commercial salt prepared from monazite for use in the manufacture of the incandescent mantles is thorium nitrate containing some cerium. Owing to the increased demand and production of this salt its price fell within a few years from £50 to £3 per kilogram.

As to the output of monazite-sand no very exact statistics are available. The amount exported annually from Brazil is about 5000 tons; and in the Carolinas the production is slowly decreasing, amounting now to about 200 tons per annum. The price varies with the percentage of contained thoria; for lower grades it was (about ten years ago) £30 per ton, and for sands containing over 6 per cent. thoria £60 to £65 per ton; since that time the prices have fallen considerably.

In this place we may mention a few other minerals which contain the rarer elements. *Columbite* is a niobate of iron $FeNb_2O_6$, in which the iron is in part replaced by manganese and the niobium by tantalum. It forms black, rhombic crystals, which occur embedded in granite at Bodenmais in the Bavarian Forest, Miask in the Ilmen Mountains in the Urals, Haddam in Connecticut, etc. With the replacement of niobium by tantalum there is a gradual passage from columbite to the closely allied rhombic mineral *tantalite*, $FeTa_2O_6$. This is of rarer occurrence, but within recent years it has come to be of considerable importance as a source of the metal tantalum, now extensively used for the metallic filaments of incandescent electric lamps. *Yttrotantalite* is a tantalate of yttrium and erbium with calcium and ferrous iron; it is found as black masses at Ytterby and Finbo in Sweden. *Koppite* forms small cubic crystals in limestone at Schelingen in the Kaiserstuhl, Baden; it contains niobic acid in combination with cerium, lanthanum, didymium, calcium, ferrous iron, potassium, and sodium. *Eudialyte* occurs as rose-red to brownish-red, rhombohedral crystals and compact masses in nepheline-syenite at Kang-

erdluarsuk in Greenland and the Kola peninsula in Finland; it contains silica, zirconia, ceria, ferrous oxide, lime, soda, and chlorine. *Gadolinite* is found as large rough crystals and as compact masses with a black colour and pitchy appearance. It is found in granite at Ytterby and Falun in Sweden, Hitterö and Sætersdalen in Norway, in Llano Co., Texas, and Mohave Co., Arizona. Crystals sometimes reach a weight of 40 pounds, and compact masses as much as 200 pounds. This mineral is a silicate of yttrium earths, beryllium, and ferrous iron; and it has been worked as a source of the rare yttrium and erbium earths used in the Nernst lamp. Optically isotropic and birefringent varieties of the mineral occur; the former when heated suddenly glows brightly and is transformed into the birefringent variety.

Hydrous Phosphates.

Struvite. After the great fire of Hamburg in the year 1842, large numbers of beautiful, colourless to yellow crystals were found in peaty earth intermixed with cattle-dung amongst the foundations of the St. Nicholas church. These were named struvite, after the Russian minister then at Hamburg. Since that time similar crystals have frequently been found in old dung-heaps and sewers, and, under more natural conditions, in deposits of guano. Chemical analysis led to the surprising result that these crystals were identical in composition with a substance which had long been known to chemists, and obtained by them in the ordinary course in the analysis of magnesium salts, namely ammonium magnesium phosphate $(NH_4)MgPO_4 . 6\ H_2O$.

These crystals (plate 82, figs. 3 and 4) attract attention by reason of their curious coffin-like shape. They belong to the rhombic system, but being differently developed at their two ends they fall in the hemimorphic class of this system (like hemimorphite, p. 131). At one end of the vertical axis they are bounded by a large basal plane, and at the other end by dome faces. As we have already seen (pp. 131, 246) crystals which show such a hemimorphic development are pyro-electric, the two ends becoming charged with positive and negative electricity with changes of temperature.

On exposure to the air the crystals become dull, white, and opaque (fig. 4), owing to loss of water and ammonia; and for this reason they should be preserved in sealed vessels. The material is insoluble in water, especially in the presence of ammonia; and on this property depends the use of this compound for the quantitative determination of magnesium. Before the blowpipe it fuses, with the evolution of water and ammonia. The specific gravity is 1·7, and the hardness between that of talc and gypsum.

Crystals of struvite have also been found in dung pits at Homburg-vor-der-Höhe, Brunswick, and Marburg; in sewers at Dresden; in bat-guano in the Skipton Caves near Ballarat in Victoria, Australia; and in the guano deposits of the island of Ichaboe, on the west coast of Africa. At the last-named place the crystals are associated with another similar compound, namely "salt of phosphorus", $HNa(NH_4)PO_4 . 4\ H_2O$, which as a mineral is known as stercorite.

Vivianite. This is the most abundant of the several minerals which contain iron in combination with phosphoric acid. Crystals were first found in Cornwall and were sent by J. G. Vivian in 1817 to A. G. Werner, who accordingly named them vivianite. Previously the mineral had been known only as a blue, earthy material under the name "blue iron earth".

The crystals are monoclinic and isomorphous with those of erythrite (p. 177); they are usually small, and occur singly as attached crystals, or they may form radially fibrous or almost globular aggregates (plate 82, fig. 6). There is a perfect cleavage parallel to the plane of symmetry: fig. 5 of plate 82 shows a cleavage fragment from an unusually large crystal. The hardness is the same as that of gypsum, and the specific gravity is 2·6. The colour ranges from bluish-green to deep indigo-blue; the crystals are, however, originally colourless, and only acquire the blue colour on exposure to the air. This change in colour is due to a chemical alteration of the material of the crystals. Pure vivianite is a hydrated phosphate of ferrous iron, $Fe_3(PO_4)_2 . 8 H_2O$, but when exposed to the air for some time the ferrous oxide becomes partly oxidized to ferric oxide. The amount of the ferrous oxide may diminish from 43 to 10 per cent., with a corresponding increase in ferric oxide from 1 to 38 per cent.

Cleavage flakes of vivianite are well suited for demonstrating the phenomenon of dichroism. A fragment from a blue crystal when rotated with the stage of the microscope over the polarizing nicol shows a change from almost colourless to deep indigo-blue.

By blowpipe tests all the constituents of the mineral can be easily detected. Heated in a bulb-tube, the mineral gives off water; fused on charcoal, it gives a black magnetic bead (proving the presence of iron), and it imparts a green colour, characteristic of phosphoric acid, to the flame.

Vivianite is a mineral of secondary origin, and often occurs in association with organic remains. Crystals are sometimes found inside fossil shells, as at Kerch in the Crimea, and in bones in the peat-bogs of Ireland and Laibach. The crystallized group in fig. 6 is from the lignite deposits of late Tertiary age at Weckesheim in the Wetter valley in Hesse; and the specimen in fig. 5 is said to be from Moldova in Hungary. Fine crystals were formerly found in cavities in iron-pyrites and pyrrhotite at Wheal Jane, near Truro in Cornwall; and recently at Leadville in Colorado. More frequently, vivianite is met with as a pale sky-blue powder, or as a mere stain, in peat-bogs and deposits of bog-iron-ore.

Of the several other minerals which contain iron in combination with phosphoric acid or arsenic acid, the following may be briefly mentioned. They are usually associated with limonite (brown iron-ore). *Scorodite*, $FeAsO_4 . 2 H_2O$, forms small rhombic crystals of a sage-green colour; it has been found in many of the Cornish mines as a product of the alteration of mispickel. *Strengite* is the isomorphous phosphate, $FePO_4 . 2 H_2O$, occurring as small globular aggregates of minute crystals of a characteristic pale violet colour. *Pharmacosiderite*, a hydrated basic ferric phosphate, forms small, sharp cubes occasionally in combination with the tetrahedron, and of a bright green colour. This also occurs in the Cornish mines as an alteration product of mispickel.

Wavellite. This mineral was first found by Dr. W. Wavell at the end of the eighteenth century in crevices of a black slaty rock near Barnstaple in Devonshire. Crystals are rhombic, but only very rarely are they distinctly developed. As a rule the mineral forms radially-fibrous aggregates with a hemispherical or globular exterior. The hemispherical masses occur attached by their flat surface to the rock; and the globular masses are sometimes grouped together like a bunch of grapes. Again, if the mineral has grown in a confined fissure it gives star-like groups on the flat surface of the rock. Such forms are extremely characteristic of the mineral wavellite. The colour is often a delicate shade of green, passing at times into white, grey, or yellowish. The specific gravity is 2·3, and the hardness $3^1/_2$—4. In composition, wavellite is a hydrated basic phosphate of aluminium with the formula $4 AlPO_4 . 2 Al(OH)_3 . 9 H_2O$.

Wavellite is found in crevices of sedimentary rocks: for example, in clay-slate in Devonshire and Co. Cork; in quartz-slate at Langenstriegis near Freiberg in Saxony; in

sandy greywacke at Cerhovic near Beraun in Bohemia. In association with iron ore, it is found in the Rothläufchen mine at Waldgirmes near Wetzlar, and at Oberscheld near Dillenburg in Nassau. The specimen represented in plate 82, fig. 9, is from Montgomery Co., Arkansas.

Lazulite. This mineral, popularly known as blue-spar, receives its name from the characteristic sky-blue colour. Care must be taken not to confuse this name with the very similar name lazurite (p. 258) applied to quite a different mineral. The crystals are monoclinic, and usually consist of a combination of two hemi-pyramids, producing a form very similar to a rhombic pyramid (plate 82, fig. 8). When one of these hemipyramids is more largely developed the habit of the crystals may be prismatic (fig. 7). From the shape of its crystals, lazulite can always easily be recognized: crystals are, however, rare and the mineral is more often massive and granular. The colour is bluish-white, sky-blue, or indigo-blue, and the material is only slightly translucent. Attached crystals have brilliant surfaces, but embedded crystals are dull and rough. The specific gravity is 3·1, and the hardness 5—6. Lazulite is composed mainly of aluminium phosphate, but in addition to this it contains ferrous oxide (2—12 per cent.), magnesia (8—13 per cent.), and some water, the formula being $(Fe,Mg)O \cdot Al_2O_3 \cdot P_2O_5 \cdot H_2O$. The best known localities are Werfen in Salzburg, and Graves Mountain in Lincoln Co., Georgia (plate 82, figs. 7 and 8).

Wavellite and lazulite find no practical applications. Other hydrated aluminium phosphates are turquoise (plate 82, figs. 10—12) and variscite (plate 82, fig. 13): these have already been described (p. 260).

Organic Compounds.

Honey-stone or Mellite. Like the minerals just considered, this also contains alumina, but instead of being combined with a so-called mineral acid we have here an organic acid or carbon compound. This acid, is known as mellitic acid, and the mineral is a hydrated mellitate of aluminium, with the chemical formula $Al_2C_{12}O_{12}.18H_2O$. The name honey-stone was first given by A. G. Werner in 1789, on account of the honey-yellow colour of the mineral; and the name mellite, derived from the Greek, has the same meaning.

Crystals of honey-stone are very simple in their form. They belong to the tetragonal system, and are bounded by a single square pyramid (plate 82, figs. 14 and 16), or this pyramid in combination with a prism of the second order (fig. 15). The faces of the pyramid are inclined to one another at an angle of $118^1/_4{}^0$; this is chosen as the primary pyramid P, and the symbol of the prism then becomes $\infty P\infty$.

The colour is straw-yellow or honey-yellow to brownish, rarely white; and the transparency of the crystals is usually impaired by internal cracks. The specific gravity is 1·6, and the hardness slightly over 2. The mineral is readily soluble in nitric acid and in hydrochloric acid. When heated in a bulb-tube it gives off much water; and before the blowpipe it becomes charred and leaves a white residue of alumina.

Honey-stone is found embedded in lignite (brown-coal) at Artern in Thuringia (plate 82, fig. 14), and Luschitz in Bohemia; and in an earthy black coal at Malovka in government Tula, Russia (figs. 15 and 16).

Whewellite. This is the calcium salt of another organic acid, the well-known oxalic acid of frequent occurrence in the vegetable kingdom: it is a hydrated oxalate of calcium with the formula $CaC_2O_4.H_2O$. The mineral was named after William Whewell (1794—1866), philosopher and historian of science, who for a time was professor of mineralogy at Cambridge. The small monoclinic crystals are beautifully developed with a profusion of bright facets, and often form pretty heart-shaped twins resembling those of calcite. They are colourless and water-clear and possess a double refraction very nearly as strong as that of calcite.

Whewellite is found in the crevices or joints of the rocks, and sometimes in the coal itself, of coal mines; these crevices are partly filled with calcite, dolomite, barytes, and other minerals. It is known only from a few localities in Saxony (Burgk near Dresden, and Zwickau) and Bohemia (Brüx, and Schlan), and at Markirch in Elsass.

Amber, or Succinite, represents the resin which oozed from the pine-trees of past ages; this has been preserved in a fossil condition, whilst the trees themselves have vanished, leaving behind no more than mere traces of their former presence. Being of vegetable origin, this fossil resin is not, strictly speaking, a mineral; nevertheless it is usually regarded as such, for it is found in the rocks of the earth's crust and it shows no organic structure. Further, it has always, even in prehistoric times, been much in favour as a gem-stone for

personal ornament. But being a resin it shows no regular crystalline form such as we associated with true minerals. It acquires only such forms as are produced by the flow of a viscous substance; as seen, for example, in the drops of resin which exude from pine-trees and cherry-trees at the present day.

Occasionally there are found well-defined drops or "tears" of amber (plate 82, fig. 22), but usually the material is found as irregular masses ranging from a gram to ten kilograms in weight. Sometimes the material shows a platy or shelly structure ("shelly amber", plate 82, fig. 17), due to the material having become partially hardened in the intervals between successive flows. Such material can be easily broken along these layers: it is always clear and frequently encloses foreign bodies. As distinct from this we have "massive amber", which may be either clear, transparent, and uniformly coloured, or more or less cloudy and opaque and with an irregular distribution of colour. "Clear" amber is perfectly transparent and pale yellow to reddish-yellow in colour; but this is of rare occurrence. "Cloudy" amber is separated into the following varieties: "bastard", "osseous", and "frothy"*).

The "bastard" variety is distinguished by the high degree of polish it is capable of taking. According to the distribution of the cloudiness, several sub varieties are recognized. In the "true bastard" the material is uniformly clouded throughout. In "clouded bastard" (plate 82, fig. 20) coloured cloudy patches are distributed through a clear groundmass. In the variety known as "flomig" the cloudiness is distributed as a fine dust throughout the material. A further subdivision of "bastard" is based on differences in colouring. Pieces of a pure white to greenish-yellow shade are described as "pearl-coloured"; and of these the paler are known in the trade as "blue" amber, and the yellower as "kumst-coloured" (Kumst being an East Prussian name for cabbage or Sauerkraut).

"Osseous amber" or "bone" is opaque, softer than "bastard", and less capable of taking a polish. It resembles bone or ivory in appearance, and ranges in colour from white to brown (plate 82, fig. 21). "Frothy amber" is opaque, very soft, and not susceptible of a polish.

Cloudy and "flomig" amber, but not the "osseous", can be clarified by heating the material in oil. The tiny pores in the amber become filled with oil and allow the free passage of the light rays without these being scattered. Much of the material is ruined by the process; the heating and cooling have to be effected very gradually, and care must be taken not to reach the boiling point of the oil. The product so obtained, especially that given by the "blue" trade variety, is as clear as glass, and it has been used for making magnifying lenses, spectacles, prisms, and burning glasses. An amber burning glass fires powder much more quickly than one made of glass. The fact that clarified amber possesses a higher refractive power than raw amber is explained by the presence of the oil. This process of clarifying amber was known to the ancients; Pliny mentions that amber when boiled in fat acquires a greasy appearance like that of a sucking-pig.

During the operation of clarifying amber there are often developed in the interior of the stone peculiar cracks bearing a resemblance to fish scales, which produce an iridescence or the total reflection of the light. These cracks are known to the amber workers as "sun-spangles".

Cloudy amber can also be rendered clear by the application of dry heat. The pieces are embedded in sand and heated for a long time at a temperature over 100° C.; this process being similar to that adopted for changing the colour of amethyst and topaz. The resin thereby becomes softened and the pores closed up.

*) On the trade varieties of amber see R. Klebs, "Die Handelssorten des Bernsteins." Jahrb. der königl. preuss. geologischen Landesanstalt, for 1882.

This property of softening, possessed by amber when warmed, is made use of for the purpose of uniting small fragments into larger pieces. By heating the material away from the air and under a pressure of 3000 atmospheres, objects of all shapes and sizes and with a highly polished surface can be moulded. This product is known as pressed amber or ambroid.

Enclosures of foreign bodies in amber are of special interest, and fossil insects are often beautifully preserved in this material. Those most commonly met with are diptera (plate 82, fig. 19, and text-fig. 274, both enlarged three times), and less frequently orthoptera. neuroptera, coleoptera, etc., and arachnida (a spider is shown in text-fig. 275). Plant remains, such as pine-needles, catkins, etc., are also found enclosed in clear amber. The forms of these enclosures indicate that at the time they became embedded the resin must have been quite fluid. The bodies of the insects have perished, leaving only impressions with a little of the chitinous material preserved. Minute crystals of iron-pyrites also occur embedded in amber, particularly in the osseous variety.

Fig. 274.

Fig. 275.

Insects enclosed in Amber.

Amber is composed of carbon (79 per cent.), hydrogen (10·5 per cent.), and oxygen (10·5 per cent.); and this percentage composition can be expressed by the formula $C_{10}H_{16}O$. It is to be remembered, however, that amber is not a definite chemical compound, as might be suggested by the above formula. As proved by the selective action of various solvents, it is an intimate mixture of different substances. Alcohol dissolves 20—25 per cent. from clear amber, and ether 18—23 per cent.; the insoluble portion consists of succinine or amber-bitumen (44—60 per cent.) and succinic acid (3·2—8·2 per cent.).

The physical characters of amber present certain remarkable features. It has long been known that the material becomes electrified when rubbed, then attracting to itself particles of dust and other light objects. On this account the Greek name *elektron* (ἤλεκτρον) for amber is probably derived from ἕλκητρον, the drawer; and the modern word electricity is from the same root. The hardness is low, being rather less than that of calcite; still the material is capable of taking a high polish. The specific gravity amounts to no more than 1·08, being just the same as that of sea-water; and for this reason amber is readily raised and transported from its bed in the sea. For the Röntgen rays amber is one of the most transparent of substances. Certain specimens, especially those from Sicily, are strongly fluorescent, appearing bluish-green by reflected light, in a manner similar to petroleum.

Amber melts at 287° C., then decomposing and giving off succinic acid and other volatile constituents. The black substance that remains behind dissolves in linseed-oil and is used for amber-lac and amber-varnish. At a higher temperature amber burns with a bright white flame, and gives a pleasant aromatic odour. The German name "Bernstein" for amber, derived from the old German "börnen", to burn, means a stone that burns.

The home of the true amber is the Prussian coast of the Baltic Sea, where since prehistoric times the material has been collected. It is also found in quite small amount on the Simeto river near Catania in Sicily, and in a few other districts; but the fossil

resins of other localities present certain points of difference from the true amber or succinite. Prussian amber occurs embedded in a stratum in the older portion (the Oligocene) of the Tertiary formation. The sandy material of this bed is rich in grains of bluish-green glauconite, and it is consequently known as a greensand or as the "blue earth" (not to be confused with the "blue ground" which forms the matrix of diamond in South Africa). This amber-bearing bed crops out on the coast of East Prussia and extends northwards beneath the sea. In the latter case the bed may be disturbed by storms, and the amber washed out and cast up on the shore. In former times also the bed was disturbed by running water and moving ice, and the amber transported and laid down again in later deposits: in this way amber has come to be distributed, though only sporadically as isolated pieces, over a wide area in the alluvial and glacial deposits of northern Germany.

The amber won in open pits or by underground mining in the blue earth is known as "pit-stone" or "earth-amber". Material collected on the seashore or drawn from the sea with the masses of seaweed is called "sea-stone" or "drawn-stone". Formerly, the amber was also collected from the floor of the sea by divers, and at one time by dredging in the Kurisches Haff. Occasionally the "earth-stone" is also found in the later Tertiary and glacial deposits; and in this case the material is covered with a thick weathered crust. This crust can be readily detached, when the fresh but reddened amber beneath is seen to be marked by numerous shallow pittings (exactly as represented in plate 82, fig. 10, although this specimen is stated, perhaps erroneously, to be a piece of "pit-amber"). Pit-amber always shows on its surface a thin white crust with a dusty weathered appearance.

During former centuries the "sea-stone" was by far the most important product, although "pit-stone" had also since very early times been obtained by digging on the land. These conditions were to some extent reversed when in 1836 the inhabitants were given the freedom of collecting amber for themselves, and a large number of open workings were then commenced. The "pit-stone" came to be of still greater importance when by the government enactment of June 1st, 1867, collecting on the shore was separated from workings on the land, and the latter were leased to the highest bidders. Mining for amber then came to be developed on a large scale at Palmnicken and Kraxtepellen in Samland, and this had an important influence on the industry. Owing to the presence of an opaque crust on the surface of the "pit-stone" the quality of the material cannot be estimated for the market, and it is necessary to first clean the product. The adhering earthy material is first removed by a stream of water, and the stones then agitated in a large vat with broom and brushwood, and lastly with sand and water in rotating barrels. In this way the impurities and the crust are removed and the product then presents exactly the same appearance as the clean "sea-amber".

For many years the winning of amber has been controlled by the firm of Stantien and Becker, and the trade varieties of amber introduced by them are universally recognized. The four main varieties depend on the size and shape of the pieces and their suitability for different classes of work. As given by the amber expert R. Klebs they are as follows.

The "flat" varieties, including the so-called "tiles" (Ger. Fliesen) are the most valuable: here the pieces of sound amber have a thickness of at least $5^1/_2$ centimetres and a length and breadth of 25 cm. Such pieces are used preferably for making cigar-holders, the larger in Vienna, which is the principal centre of the amber working industry, and the smaller in Nürnberg and other German towns. Similar to these in form but not so thick are the "plates" (Ger. Platten), which are mostly used for making the mouthpieces of wood or meerschaum cigarette-holders; also for the so-called "manelles" consisting of a flat polished disc with a hemisphere in the centre; and the so-called "horse-corals" or flat beads which are much worn in Russia.

The "medium" varieties, in which the "shelly amber" finds a place, are worked mostly as beads. Such material is especially valuable when clear pieces enclose well-shaped insects.

The "round" varieties form the material for different kinds of beads, including the elongated "olives" and "Zotten", and the spherical beads proper.

Amber beads have been used as personal ornaments at all periods and by all races. In many districts in Germany the well-to-do peasant women regard a string of amber beads (known as corals) as the most valuable of ornaments; and the same is the case in Persia, China, Tartary, and many other countries. Or again, in the form of rosaries, the beads are used for religious purposes. The Mohammedan rosary is a string of ninety small beads and one large bead, and 70,000 such strings are sold each year. The beads are also sometimes cut with facets and mounted as brooches and various other ornaments, or used for the decoration of mirrors and picture-frames.

The variety known as "varnish" consists of the smallest pieces not large enough for making into beads. Such material is fused for the preparation of amber-varnish and lac.

The production of amber during the year 1896 amounted to about 440 tons. By far the larger part of this was obtained by the firm of Stantien and Becker from the mines at Palmnicken and Kraxtepellen. Small quantities were obtained by dredging and were collected on the seashore. During 1890, as stated by Klebs, 90,000 cubic metres of the blue earth were raised, yielding about 202,000 kilograms of amber, of the value of about £90,000. The amber industry in East Prussia gives employment to some 1200 persons.

Ozocerite. The last substance to be described here shows a close similarity to wax and paraffin, and is hence known as mineral wax or native paraffin. The more common name ozocerite, derived from the Greek, means to smell of wax. It forms brownish or greenish, translucent masses, and readily melts and burns like wax or paraffin. At Boryslaw in Galicia and Slanik in Roumania it occurs together with petroleum in considerable quantities, and is there won by mining. The crude material is purified by treatment with sulphuric acid; and the product, known as ceresine, employed for the manufacture of candles, tapers, artificial honeycomb, etc. The annual production amounts to about 8000 tons. Ozocerite is a mixture of various hydrocarbons and cannot therefore be regarded as a mineral species. Still less can petroleum, asphaltum, and coal find a place amongst simple minerals. These have originated from vegetable or animal remains, and they are not definite chemical compounds. Although they are of such great economic value, we must here exclude them from the mineral kingdom, in which we have treated only of simple minerals of definite chemical composition and of inorganic origin.

Appendix.

The Formation of a Collection of Minerals.

The pictures given on the accompanying plates cannot of course entirely take the place of the actual minerals. In a way they are comparable with the show specimens exhibited in a public collection, which can be viewed only at a distance through the glass panes, but cannot be handled and examined more closely. In order to acquire a true knowledge of minerals it is necessary that their actual material should be handled and studied. Here the student possesses an advantage over the amateur in having access to the teaching collections and students' series; but even he will become more intimately acquainted with minerals and take a greater interest in them, if the specimens form part of his own collection. It is not at all necessary to acquire fine and expensive pieces. A simple specimen is sufficient to show the prominent and essential characters of a species, and help to impress them upon the mind. A comparison of such specimens with the pictures and descriptions in this volume will also be of assistance.

A keen collector will find that his collection quickly grows, and not necessarily with the expenditure of much money. Specimens of inferior quality collected at an early stage will gradually become replaced by better examples of the same species from the same locality. If, however, such inferior specimens have been collected by oneself they possess a personal interest and are valuable in giving a reliable record of the locality at which they were found; furthermore, they help to remind the collector of the place of origin and the mode of occurrence. In very nearly all districts minerals of one kind or another can be collected or purchased from quarrymen or miners. Others may be acquired by exchange from the collectors in other districts; and still others from the mineral dealers. The object of collecting is not to satisfy the mere greed for possession, but to supply the collector with material which will always be at hand for purposes of study and comparison, and with specimens of whose beauty he can never tire.

In his young days nothing gave the author greater pleasure than to sit before his collection and regard the specimens. His earliest acquired minerals were treasured in matchboxes kept in a small cupboard; they next occupied the inside of an old clavichord; and when this became too small for the collection his parents gave to him a real mineral cabinet with forty drawers. During the school holidays he was allowed by Professor Dunker to visit the mineral collection in the university of Marburg; entering with a feeling of awe every time he found the door open, and bitterly disappointed when he found it closed. Passing from case to case admiring the displayed treasures, he little dreamt that one day he would become an assistant in that collection with the privilege of seeing the specimens every day.

Anyone interested in minerals should not miss an opportunity of visiting a public collection. A comparison of the specimens with the pictures in this book will help much to impress upon the memory the characters of minerals. It will be found that the specimens represented on the coloured plates are all very good examples;*) and if these were brought together as a type collection they would no doubt serve a useful purpose in connexion with the set of plates. But such a collection could not replace a collection of one's own; it shows the most typical and best examples, and places an ideal before the private collector.

The cleaning, labelling, and setting out of the specimens in a collection are points of importance. No very definite rules can, however, be laid down, and much must be left to individual taste and judgment.

For cleaning and dusting the specimens a soft painter's-brush and a brush with shorter and stiffer bristles — a plate-brush is excellent — will be found useful. In many cases the specimens may be washed in water or placed under the tap; but care should be taken not to use hot water as cleavage cracks may be developed in the crystals. A lather of soap may be applied with a soft shaving-brush; and some specimens may be scrubbed with a hard nail-brush. The use of acids should be avoided, except in very special cases, for some of the associated minerals may be decomposed or tarnished, and the specimen would then no longer be in its natural condition.

The specimens may be trimmed to a suitable and presentable shape with a small hammer. Here great care is required, for the crystals on the surface are very liable to be fractured along the cleavage by the concussion. Crystals should stand out to advantage on the matrix; but the mistake is often made of reducing the specimens to too small a size, or even of detaching the crystals from their matrix. The associated minerals should always be preserved, since they tell much as to the origin of the minerals.

Care must be taken that the specimens are not allowed to knock one against another, otherwise the edges of the crystals will be bruised and the specimens ruined. To avoid this, each specimen should be carefully laid in a separate card-tray. The inner part of a match-box serves this purpose; or trays can be easily made at home out of cardboard pasted round with paper. Neater card-trays are supplied very cheaply by the mineral dealers and box makers. A glazed paper used for lining the trays has the advantage that it can be readily wiped free from dust; but at the same time the specimens slide about more easily. The card-trays should be of such a size that when placed in rows they exactly fill the drawer, thus preventing any movement as the drawers are opened and closed. Depending on the size of the drawers, a unit size of card-tray must be selected and all others made of multiple or sub-multiple sizes; so that a larger tray may be replaced by two, four, or more smaller ones as the specimens require. The depth of the trays may be $^1/_2$—$^3/_4$ inch. Small isolated crystals are conveniently kept in corked glass-tubes.

An important duty is the careful labelling of the collection, Each specimen should be accompanied by a neatly written label — a thin card with a black line border is effective. On this should be recorded the name of the mineral, the locality where found, the source of the specimen (by whom collected, or the name of the donor), and the date. If desired, further information may be given respecting the associated minerals present on the specimen,

*) In the original German edition of this work it is stated in the explanations of the plates in which collection each of the specimens figured is to be seen. This information, being of less immediate value to English readers, has been omitted in the present edition. The collections named include those at Bonn, Clausthal, Frankfurt, Giessen, Göttingen, Hamburg, Karlsruhe, Marburg, and Stuttgart, and the private collections of Professor V. Goldschmidt at Heidelberg, Professor A. Nies at Mainz, and Dr. G. Seligmann at Coblenz.

the forms of the crystals, the mode of occurrence, etc. Original labels should always be carefully preserved and kept with the individual specimens to which they refer; they often afford important evidence as to the authority for the statement of locality. A difficulty with loose labels is the danger of their being interchanged, and, when mixed, to discover to which specimens they really belong. The only way to avoid this is to attach a small label to the specimen itself. This may give a brief statement of the locality and other essential details, or simply a number; the same number is written on the loose label, and if desired also in a catalogue or register of the collection.

An attempt should be made to represent at least the more important varieties of each species, its different forms of crystals, modes of occurrence, associations, etc. The common or massive forms of a mineral should be represented in addition to rarities in the way of crystals. The classification followed may be taken from the text-books; and it will be found extremely instructive to re-arrange the collection according to different systems of classification. The subdivision of each species is best made according to the localities where the specimens were found, commencing with those nearest home. But when the collection has grown to this extent the collector will find himself compelled to specialize on certain lines. He may restrict his collection to the minerals of a particular district or country, to certain groups of minerals, or even to a single species; an exhaustive collection of calcite, for example, might fill a whole museum.

When setting out to collect minerals in the field a certain amount of equipment must be carried. At least two hammers are required; a larger one weighing about $1^1/_2$ pounds and a smaller one of a few ounces, the former being for ordinary use, and the latter for trimming the specimens. The hammer-head is square at one end and chisel-shaped at the other, and of steel specially hardened at the ends. A chisel with a hard edge is also required. A third still larger hammer — a sledge-hammer — is often useful for breaking large blocks of stone. Other items include a canvas collecting-bag with several pockets, a magnifying lens, a map, and note-book, and last but not least plenty of packing material. An acid bottle is often of assistance in recognizing carbonate minerals and limestone rocks.

For packing material old newspapers are the best, and for any specially delicate specimens a few small boxes should be carried. The specimens must not be allowed to rub against one another in the collecting-bag, but each one must be carefully and separately wrapped up. At the same time a temporary label, indicating the spot where the specimen was found should be enclosed in the wrapping. Some collectors prefer to mark a number on the specimen or on the wrapping, and a corresponding entry in a note-book. When several specimens are collected at the same spot these may be conveniently placed together in a paper bag with a note on the bag, each specimen being separately wrapped. Each collector has of course methods in detail of his own, and he soon finds out those best suited to his particular purpose. When away on a collecting trip for several days, the results of each day's work should be labelled in more detail after the evening meal. A good plan is to place thin adhesive labels written in ink on each specimen (the gummed paper from the edge of postage stamps is excellent for this purpose). It may then be convenient to send the specimens home by post or rail, when they will have to be more carefully packed. Plenty of crumpled newspaper forming a cushion round each specimen is the best. Delicate specimens should be wrapped first in tissue-paper and surrounded by a layer of cotton-wool before the wrapping of newspaper; and it is often advisable to place these in a separate box before packing them with other specimens. A point of the utmost importance is that the box of specimens should be completely filled and tightly packed, all the spaces being filled with paper, hay, or straw, before nailing down the lid. If this is not done the specimens will become displaced and damaged during transit.

When the collector returns home with his treasures he can proceed to clean and trim the specimens and examine them at his leisure. Small crystals of some rare mineral not noticed before in the field may perhaps be then detected with the aid of a lens. Before the specimens can be completely labelled, the minerals present must be determined. This can be done by observing their prominent characters, such as crystalline form, hardness, lustre, cleavage, etc., and if need be they can be examined before the blowpipe (p. 63). Reference may be made to books and tables on determinative mineralogoly; and in case of difficulty an earnest student will always find willing help from his teacher or from the curators of public collections.

Only in exceptional cases are mineral specimens of any value to be found amongst the weathered materials on the surface of the ground. Search must be made at spots where unweathered rocks are exposed, as in mines, pits, quarries, railway cuttings, etc., or where there have been recent falls of cliffs. In particular, many good specimens are often to be found on the waste heaps from metalliferous mines. Further' it is mostly amongst the older sedimentary rocks and those of igneous and metamorphic origin that crystallized minerals are to be found. For this reason there is very little of interest in the way of minerals to be found in the neighbourhood of London; but the mining districts of the west and north of England, particularly in Cornwall and Cumberland afford many opportunities for collecting.

In the original German edition of this work an account is given of the several places in the neighbourhood of Giessen where minerals may be found and collected. But here we must leave the collector to plan out for himself the collecting trips which may be made in his own neighbourhood. Detailed information as to mineral localities in the British Isles will be found in R. P. Greg and W. G. Lettsom, 'Manual of the Mineralogy of Great Britain and Ireland' (London, 1858), and T. M. Hall, 'The Mineralogist's Directory' (London, 1868). Other useful books are: J. H. Collins, 'Handbook to the Mineralogy of Cornwall and Devon' (Truro, 1871), with supplement in the Journal of the Royal Institution of Cornwall, 1911, vol. LVII; M. F. Heddle, 'The Mineralogy of Scotland' (2 vols., Edinburgh, 1901). Similar works on topographical mineralogy have been written for other countries.

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